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Operation UPSHOT-KNOTHOLE

NEVADA PROVING GROUNDS

March - June 1953

Project 3.9

FIELD FORTIFICATIONS

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(21) Report on

OPERATION UPSHOT-KNOTHOLE

Project 3.9

(6) FIELD FORTIFICATIONS

~~REPORT TO THE TEST DIRECTOR~~

by

(10) Allan R. Fowler and Daniel R. Muller

(11) Dec 54

(12) 262 p.

December 1954

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Fort Belvoir, Virginia

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ABSTRACT

Project 3.9 had four objectives, each directed toward filling a particular gap in the knowledge of atomic effects on and in field fortifications. Because each objective necessitated an independent experimental set-up and essentially constituted a test within itself, the report is presented in four parts: ~~Part I,~~ (1) General Effects on Field Fortifications; ~~Part II,~~ (2) Pressure Measurements in Field Fortifications; ~~Part III,~~ (3) Reflected Thermal Radiation in Foxholes; ~~Part IV,~~ (4) Gamma Radiation in Foxholes.

The objective of Part I was to supplement previous tests by obtaining qualitative evidence showing the detailed atomic effects on field fortifications with overhead cover and revetment. In presenting the background, the important past tests were summarized; and the summary was extended in Appendix G, where an attempt was made to establish blast damage curves suitable for inclusion in TM 23-200 by applying a statistical analysis to the observations of blast damage made in Exercise DESERT ROCK I to V. To supplement past tests and accomplish the objective, two types of construction and a variety of common materials were used for the revetment and overhead cover of fifty test structures. These structures represented three types of field emplacements - the command post, machine gun emplacement, and two-man foxhole. From the test, a detailed evaluation of the damage done to the structures was consolidated with observations made in past tests; and qualitative conclusions were drawn on the vulnerability of these types of fortifications to the effects of an atomic explosion. Recommendations were made concerning procedure to be followed in the event of future testing of improved fortification designs; future testing of the present (FM 5-15) type was considered unnecessary.

The objective of Part II was to study the magnitude and characteristics of overpressure build-up in field fortifications. The peak overpressures recorded by the Wiancko pressure-time gages within the open two-man foxholes were between 1.87 and 1.55 times the incident overpressure at ground level. Peak pressure measurements made with indenter gages on the walls and floors of these foxholes indicate few overpressures unusually higher or lower than those indicated above. It is recommended that no further testing be conducted unless the physiological effect of these overpressures on a human is shown to be significant.

The objectives of Part III were to make measurements of the reflected thermal radiation within open two-man foxholes and to

determine a method of scaling to a range of possible situations. It is possible to predict the reflected thermal energy distribution in foxholes for any atomic weapon yield, height of burst, distance from ground zero, and reflectance of the foxhole walls. If the reflectance is one third or less, a man will receive less than 10 per cent of the direct thermal radiation provided he is in the shadowed portion of the foxhole at least 1 ft below the limit of the direct thermal radiation on the exposed wall. It is recommended that the results of this experiment be considered conclusive unless a requirement is shown for the thermal energy distribution in an emplacement with a markedly different geometry.

The objective of Part IV was to determine the angular dependence of prompt gamma radiation instrumentation in open two-man foxholes. The average difference between the gamma radiation intensity measures with the vertical and horizontal film packets was 19 per cent; and, between the vertical and 45° film packets, it was 21 per cent. It is concluded that the angular orientation of film badges used to measure gamma radiation in a foxhole is not a critical factor in determination of the total dose. It is recommended that the angular orientation of film badges be considered not to affect the conclusions of Project 2.6, BUSTER.

FOREWORD

This report is one of the reports presenting the results of the 78 projects participating in the Military Effects Tests Program of Operation UPSHOT-KNOTHOLE, which included 11 test detonations. For readers interested in other pertinent test information, reference is made to WT-782, Summary Report of the Technical Director, Military Effects Program. This summary report includes the following information of possible general interest:

a. An over-all description of each detonation, including yield, height of burst, ground zero location, time of detonation, ambient atmospheric conditions at detonation, etc., for the 11 shots.

b. Compliation and correlation of all project results on the basic measurements of blast and shock, thermal radiation, and nuclear radiation.

c. Compilation and correlation of the various project results on weapons effects.

d. A summary of each project, including objectives and results.

e. A complete listing of all reports covering the Military Effects Tests Program.

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PART I

GENERAL EFFECTS ON FIELD FORTIFICATIONS

CHAPTER 1

INTRODUCTION

1.1 OBJECTIVE

The objective of Part I of Project 3.9 was to supplement previous tests by obtaining qualitative evidence showing the detailed atomic effects on field fortifications with overhead cover and revetment.

1.2 BACKGROUND

1.2.1 General

There were several atomic effects tests on field fortifications and related structures conducted prior to UPSHOT-KNOTHOLE. These tests fell into three general categories: gross effects on standard (FM 5-15) field fortifications, physiological effects within foxholes, and effects on civilian type shelters.

Large numbers of standard field fortifications were exposed to atomic explosions as a part of the various DESERT ROCK exercises. However, the recording of the atomic effects on these fortifications was a mission secondary to troop indoctrination and orientation; and the reports on the exercises include only a minimum of detailed information. Other large-scale tests on field fortifications were limited to those directed toward recording physiological effects within foxholes. Although much conclusive information was gained and recorded on nuclear radiation, these tests were not entirely successful in gaining conclusive information on other effects. Finally, tests on civilian shelters comparable to field emplacements furnished the large part of the detailed information on the reaction of overhead cover and revetment to atomic explosions.

In order to provide an overall picture, as well as an easy reference to those past observations consolidated with the observations made in this test, the past test reports are summarized. The summary is extended in Appendix G, where the consolidated DESERT ROCK data is presented in the form of damage criteria curves.

1.2.2 Exercise DESERT ROCK I(1)

This exercise was conducted at the Nevada Proving Grounds in the fall of 1951 in conjunction with BUSTER-JANGLE. The objective of this exercise was "to test current doctrines to the extent afforded, to determine the effect of an atomic weapon on equipment and materiel, to indoctrinate personnel, test their psychological reaction during the tactical employment of the weapon, and to the degree possible to determine what physical protective measures can be taken against the weapon."

As a part of that exercise, all normal types of tactical field fortifications were constructed and exposed at ranges from 1000 to 5000 yd from ground zero. Film badges and JS-1 thermal indicators were installed in emplacements to roughly indicate the amount of nuclear and thermal radiation received. Animals were placed at ground level, below ground level, and in shelters. From the test, an evaluation of damage to emplacements was made. Through the use of test animals and indicators, an estimate of the probable effects on personnel under varying conditions of shielding was made. The test conditions were estimated as 21.5 KT at a height of burst of 1417 ft giving 6 psi, 40 cal/cm^2, and 700 r incident at 1020 yd from ground zero.

It was concluded that: "An atomic weapon of the yield employed in Exercise DESERT ROCK and detonated at similar height will cause very few, if any, casualties beyond 1000 yd from ground zero, when personnel and equipment are well dug in on the battlefield and alerted to a possible attack. Physical protective measures currently employed by our forces are adequate to include normal field fortifications, revetments of all types, and present types of military equipment."

1.2.3 Exercises DESERT ROCK II and III(2)

These exercises were conducted at the Nevada Proving Grounds during the fall of 1951 in conjunction with BUSTER-JANGLE to supplement Exercise DESERT ROCK I. They were to obtain information relative to the effects of surface and underground nuclear explosions on typical army field emplacements, equipment and materiel, and to determine (insofar as possible) the probable effects on personnel.

As a part of these exercises, a few special and a multitude of standard army field emplacements were positioned from 100 to 1000 yd from ground zero and instrumented with film badges. These included revetted and unrevetted emplacements, both with and without overhead cover. From the tests, evaluations of the gross damage to the emplacements were made and the results of the gamma radiation measurements presented.

Exercise DESERT ROCK II, conducted with an estimated 1.1 KT surface burst, included the following general results: "The most distant revetted emplacement which collapsed to an appreciable degree was foxhole No. 3 at 280 yd. The most distant unrevetted foxhole which suffered serious damage was foxhole No. 9 at 515 yd. The average emplacement reduced the (gamma) dosage to 10 per cent of the dosage in the open at the same distance; indications were that overhead cover increased the protection from gamma radiation to a small degree."

Exercise DESERT ROCK III, conducted with an estimated 1.1 KT burst at 17 ft below ground surface, included the following general results: "In this test, the most distant revetted emplacement which collapsed to an appreciable degree was the two-man foxhole with overhead cover at 412 yd. The most distant unrevetted emplacement which suffered severe damage was the two-man foxhole without overhead cover at 566 yd. A substantial amount of the initial radiation following the underground shot came from the low radioactive cloud which covered the test positions. ...Along the NE line of positions, the average foxhole gave roughly 75 per cent protection from the radiation. Along the S line of positions, the average emplacement gave roughly 85 per cent protection. The per cent protection apparently depends upon how close the center of the cloud comes to a particular foxhole or emplacement."

General conclusions from the two tests are: "It is felt that the results of DESERT ROCK Exercises I, II, and III provide adequate information as to the protection afforded by normal field emplacements in this type of terrain and soil. Normal field emplacements provide about 80 per cent protection against the nuclear radiation effects of surface and underground bursts. Specially designed field emplacements for atomic warfare are not justified."

1.2.4 Exercise DESERT ROCK IV(3)

Exercise DESERT ROCK IV, the U. S. Army designation for its participation in TUMBLER-SNAPPER, was held at the Nevada Proving Grounds during the months of April, May, and June of 1952. In general, the mission of Exercise DESERT ROCK IV was a continuation of the missions of the previous three Exercises DESERT ROCK. While the principal mission of the exercise was the indoctrination of troops and observers, attention was also given to blast and thermal effects on troop equipment, materiel, emplacements, and live animals.

The exercise included fortification display areas at ground ranges between 200 and 3500 yd for Shots 3, 4, 6, and 8. The fortifications were of the normal tactical type. Animals, film badges, and equipment and materiel were placed both inside and outside of the emplacements.

Damage effects were presented in the form of tables and photographs in the report, with emphasis placed on the damage to equipment and materiel.

There was little discussion of the damage to fortifications. Applicable results and conclusions were: "Lethal effects of gamma radiation on sheep in foxholes up to 550 yd from ground zero, and lethal effects of gamma radiation on sheep above ground surface up to 900 yd from ground zero. Severe blast damage on surface of ground up to 1700 yd from ground zero (for Shots 3, 6, and 8). Troops in average hasty entrenchments at a range of 1700 yd from ground zero are believed safe from all effects of the size burst used in this exercise, provided they are 'down' at the time of burst." (Refers to Shot 4, 22 KT, 1050 air burst.)

1.2.5 Exercise DESERT ROCK V(4)

Although Exercise DESERT ROCK V was conducted at the Nevada Proving Grounds concurrently with Project 3.9, UPSHOT-KNOTHOLE, and therefore does not actually fall into the category of background, their final report has been published and is summarized here for purposes of continuity of the overall DESERT ROCK work. The following quotations should explain the scope of the fortification study made in this exercise: "In general, the mission of Exercise DESERT ROCK V was a continuation of the four previous Exercises DESERT ROCK. The principal mission of the exercise was the orientation and indoctrination of troop observers and troop participants."

Two special features of this exercise were groups of volunteer officers who occupied trenches at the closest range any known personnel have been exposed in a training situation, and the preparation of target damage estimates by instructors of the Special Weapons Course, C&GSC, for comparison with the actual damage evaluations.

The fortification layouts were extensive, ground ranges varying from 100 to 3500 yd for Shots 1, 2, 5, 7, 8, 9, and 10. Other than normal type trenches and weapon emplacements, the layouts included several types of heavily constructed bunkers. Fortifications were instrumented with film badges in NBS holders and, to a lesser degree, with passive type thermal indicators. There was extensive exposure of animals (sheep), both inside and outside of the fortifications. From the tests, the gross effects on equipment, materiel, fortifications, and animals along with the predicted effects on these items were presented in tabular form. The results of gamma and thermal radiation measurements were also presented.

The applicable general conclusions of the exercise are illustrated in the following paragraphs:

Selected officer volunteers, capable of calculating effects of atomic weapons, were positioned in trenches at 2000 yd for Shots 5 and 7, and at 2500 yd for Shot 2. The location of the trench in each case was based upon the determination of a safe distance by the volunteers using data from TM 23-200, dated 1 October 1952. The volunteer officers concluded that a trench 6 ft deep and unrevetted gave adequate protection under the given conditions, that there was no discomfort from blast or thermal effects, and that ground shock, at this distance, was not of sufficient magnitude to be of any concern.

On all shots, a diagram of the equipment display area was forwarded to the Command and General Staff School, Ft. Leavenworth, Kansas, in order that instructors of the Special Weapons Course could predict damage based on the layout of the display area, the expected KT yield, and the predicted weather. From comparing these estimates with actual damage and from the results of the officer volunteer program, it was concluded that "atomic weapons effects data found in TM 23-200, dated 1 October 1952, can be used by qualified officers to determine safe troop positions and to predict damage to equipment, emplacements, and personnel as the result of an atomic weapon detonation."

1.2.6 Report of the Protection Afforded by Field Fortifications Against Gamma Radiation from an Airburst Atomic Bomb, RANGER

This test is reported in WT-201, along with other studies made at RANGER. Because this test was essentially duplicated by a later test at BUSTER, which is summarized in Section 1.2.8 below, further discussion here is considered unnecessary.

1.2.7 Blast Injuries in Foxholes, GREENHOUSE(5)

This experiment was conducted as part of the atomic weapons tests at Eniwetok in 1951. The following paragraphs are totally or in part extracted from the report and should adequately describe the experiment:

Sixteen dogs protected in foxholes were exposed in pairs to the Item Shot in GREENHOUSE. The foxholes were of a uniform size, plywood lined, and fitted with instruments to measure blast, temperature, and ionizing radiations. They were dug 4 ft deep in coral at ranges of 400, 600, 800, 1000, 1250, and 1500 yd from zero point.

Post shot inspection showed that the two foxholes at 400 yd were about one-third filled with coral rubble. In one of these, the wall toward ground zero was pushed in about 20 degrees from the vertical, scorched on both sides at one-third the distance to the floor, and had three holes burned completely through. The foxholes at 600 yd held lesser amounts of coral stones and rubble. The plywood reinforcing walls held satisfactorily at these and all other more distant stations. Peak ground level overpressures were estimated to be about 100 psi and 30 psi, at 400 yd and 600 yd, respectively.

The blast gages used within the foxholes failed to yield useful data.

The clock mechanism in the (temperature) recorders failed in all but the two most distant stations. A definite increase in temperature (within the foxholes) was evident at 1250 and 1500 yd. Since the recorders were shielded from direct thermal radiation, it may be assumed that this represents a rise in temperature of the ambient air. Temperature increase was greater in the center of the holes than on the proximal wall. The temperature rise at 1250 yd was greater than at 1500 yd. Inasmuch as the greatest temperature rise was approximately 10 degrees (Fahrenheit), this phenomenon would have no biological significance to men or animals located near the bottom of the hole.

It was concluded that: "Under the conditions of this experiment and with the exception of the 400 yd station, the foxholes provided effective shelter against thermal and secondary blast injuries.

"With the observed brain damage not classified as a true primary blast injury, it appears that all the foxholes except the 400 yd station were protected against critical primary blast injury.

"At and beyond 1250 yd, the total gamma ray and neutron exposure in the bottom half of the foxholes was below lethal limits for the dog. Throughout the range of distance involved in these studies, the total gamma-ray and neutron dosages at the surface were in the supposedly lethal or seriously incapacitating range for dogs and man."

It was recommended that: "A thorough program with a high priority should be planned and carried out to determine the optimum designs for emergency field shelters. Animal exposures should be part of this program."

1.2.8 The Protective Effects of Field Fortifications Against Neutron and Gamma Ray Flux, BUSTER(6)

"This experiment was designed by the Corps of Engineers to evaluate the protection afforded by field fortifications against the nuclear radiations from atomic weapons." The experiment was conducted at the Nevada Proving Grounds in the fall of 1951 as Project 2.6 of BUSTER.

The experimental procedure was as follows: Standard two-man foxholes were constructed in Area 7 of the Nevada Proving Grounds at 300 yd intervals from 100 to 2200 yd from the expected ground zero of the Baker, Charlie, and Dog detonations. Each foxhole was instrumented in 10 different positions with gamma film detectors. Slow neutron detectors were placed along the center vertical axis in those foxholes which were located within 1300 yd of ground zero and fast neutron detectors in the same positions in those foxholes closer than 1000 yd. In addition, there were two-man foxholes with concrete covers and open one-man foxholes constructed adjacent to those located at distances of 400, 1000, and 1600 yd from ground zero. Also, at these specific distances, a soil pipe 48 in. long and 6 in. in diameter was sunk flush with and perpendicular to the surface of the earth. The concrete-covered foxholes were instrumented in the same manner as the open two-man foxholes, but the one-man foxhole and the soil pipe were instrumented only along the central vertical axis at depths of 16, 32, and 48 in. with gamma detectors. No neutron detectors were employed in the one-man foxholes.

Some of the more important results and conclusions of the test are presented in the following paragraphs.

"On the average, the dosages at the bottom of the fortifications were approximately 12 per cent of those at the surface. It is interesting to note that the percentage decrease at the various depths was essentially constant, despite the variation in the size of the detonations. Therefore, if the surface dosage at a point or the approximate size of the weapon were known, it is possible from this information to predict accurately exposures to personnel in open fortifications.

"Comparison of the exposures in the two-man and the one-man fortifications indicates that the exposures at different depths were directly proportional to the solid angle formed at the point of measurement by the opening of the fortifications, for distances greater than approximately 1500 ft from ground zero.

"Comparison of the exposures recorded in the concrete-covered fortification with those in the uncovered showed that the 15 in. concrete slab decreased measured dosages by a factor of about 16. This factor was calculated by considering the results in the two-man fortifications located at slant ranges of approximately 1800 and 3350 ft.

"The gamma radiation emitted during a detonation should be considered the primary nuclear hazard to personnel exposed to the burst of

this weapon. The range of the neutrons is such that they do not contribute greatly to the dosage except at those distances from a burst where the gamma radiation is already extremely dangerous.

"Analysis of the data obtained from the slow neutron detectors indicated that the neutron flux at different depths in open fortifications was essentially the same as that on the surface." (There was a marked decrease in slow neutron flux in the fortification with the 15 in. concrete cover.)

"The flux of fast neutrons, those whose energies were greater than 3 Mev, decreased with the depth of the fortification. Again, the marked decrease in the flux beneath the concrete slab was found in all cases."

1.2.9 F. C. D. A. Family Shelter Evaluation, BUSTER(7)

The Federal Civil Defense Administration family shelter evaluation under Project 9.1a, BUSTER, was designed to develop information on the degree of protection from atomic explosions afforded by simple structures which could be built by the average householder with available materials.

A total of 29 simple structures spaced 25 ft apart were built along an arc 1200 ft from the target point. Eighteen of the structures were the covered-trench type; five, metal-arch; four, wood-arch; and two, the basement lean-to type. Structural strength, materials, amount of earth cover, elevation, and orientation were varied for test purposes. The shelters were instrumented with gamma film badges, improvised deflection devices, and peak pressure recording land mine fuses.

The shelter structures were subjected to Shots Baker, Charlie, and Dog. From the tests, peak overpressures, thermal radiation, and gamma radiation readings were recorded. The effects of the explosions on the shelters were listed separately to assist in evaluating their reaction to each shot. Recorded data and structural damages were summarized in tabular form.

Some of the more important results and conclusions of the test are presented in the following paragraphs.

"Large quantities of earth cover were removed by each explosion. Amounts of cover blown off by Shot Baker varied from 30 to 60 per cent of the total cover. These quantities varied with elevation of structures with respect to natural grade. Partly above-grade shelters were affected to a greater extent. This undesirable reaction was serious, for it not only affected protection against radiation but also resistance of the structures to blast.

"Additional test data are needed on the reaction of earth cover. The test results do not show the effect of earth-arch action or whether the resistance of the mass of the earth cover contributed to the ability of structures to withstand blast. However, results did show that damage to structures was less severe when protected by even a small amount of cover. This was particularly evident where entrance structures were poorly protected but survived when covered. It appeared that if earth cover were below natural grade it would not be greatly affected by blast. Thus, lowering grade level of shelters would add considerably to their safety.

"The reaction of the earth cover affected not only the structural resistance of the shelters, but also their ability to protect against radiation. Reduced cover on the second and third explosions greatly increased radiation dosages within the shelters. Test structures were located sufficiently close to the three explosions to receive the shock an appreciable interval before all gamma radiation was absorbed.

"The entrances of all structures were considerably weaker than the shelters proper...practically all above-grade entrance construction was demolished and blown away. Debris thrown into the shelters was trapped in entrances and would not have injured occupants. It did block access to many of the shelters, and escape would have been hazardous. Some of the damage to the entrances was superficial and did not affect the protective value of the shelters, but all should be redesigned to provide resistance comparable with the capabilities of the rest of the structures.

"Scorching of parts of the entrance panels not directly exposed to the blast indicated the possibility of heat reflection of some magnitude. However, even in the shelter where the entrance side faced the blast, there was no evidence of heat entering the shelter proper.

"Wood shelters offered good resistance to blast provided they were properly protected by earth cover. They did not burn, and their resiliency permitted them to absorb shock without failing completely.

"The results obtained from the substitution of materials were satisfactory. Chicken wire and tarpaper sheathing for the sides of shelters were adequate where the spacing of supporting members was not too great."

1.2.10 AEC Communal Shelter Evaluation, BUSTER(8)

This test was conducted at the Nevada Proving Grounds in the fall of 1951 as Project 9.1b of BUSTER. The objectives of this test were to assess the effects of atomic bombs of various yields detonated in air at varying distances on a communal shelter of the design described herein, and to recommend to the Commission on the basis of the observed results a communal shelter design, deemed adequate within the limits of certain assumed risks, for construction as required at AEC facilities.

Since the test structure was a cylindrical, combination concrete and steel-pipe shelter of large dimensions, most of the results of the test are not applicable to field fortifications within the scope of this report. Those results that are applicable (such as the removal of earth cover affecting gamma radiation dosages within the shelter) do not materially differ from those presented in the preceding section of this report--1.2.8. For these reasons, as well as for purposes of brevity, further discussion of this test is not deemed necessary.

1.2.11 Hasty Type Air Raid Shelters, TUMBLER(9)

This experiment was conducted at the Nevada Proving Grounds in the spring of 1952 as a part of TUMBLER. The scope of the test is illustrated in the following quotations: "The necessity of providing

for the protection of personnel in the event of an enemy air attack against Sandia Base presents the problem of constructing adequate shelters in a short time with the facilities available to the Base Engineer. The degree of protection afforded against an atomic explosion by a trench shelter capable of being put in rapidly with powered ditchers gave rise to the desire of testing such a shelter under actual conditions." A test was set up with a primary objective: "...to determine the relative protection afforded personnel by an uncovered 'Z' shaped trench shelter versus that afforded by a covered 'Z' shaped trench shelter."

Two trench shelters, both unrevetted, one covered and one uncovered, were constructed at each of four positions located such that the actual ranges resulted as 625 ft, 1550 ft, 2725 ft, and 4925 ft from ground zero for Shot 4. "The main or middle portion of the trench shelter was dug approximately 25 to 30 ft long and 24 to 26 in. wide in both the covered and uncovered shelters. The arms forming the entrances varied from 8 ft to 11 ft in length, and were dug to a depth of 2 ft at their outer edge and sloped to the level of the floor of the main trench. One series of trenches was dug to a depth of 5 ft, and another series to a depth of 6 ft. The cover was constructed of 2 in. wood planking overlapping the sides of the main trench by at least 2 ft and overlaid with the spoil taken from the trench. The shelters were instrumented by the use of clothed dummies and film badges to observe the effects of blast and thermal radiation and to measure the value of nuclear radiation. From the test, the incident effects at the ranges listed above were tabulated as: 68 psi, 350 cal/cm^2, 77,000 r; 18.5 psi, 145 cal/cm^2, 18,000 r; 8.8 psi, 60 cal/cm^2, 3030 r; and 3.9 psi, 20 cal/cm^2, 183 r, respectively.

Some of the more important conclusions of the test are presented in the following paragraphs.

"The covered trench shelter affords greater protection against atomic effects, particularly gamma radiation, than does the uncovered trench shelter.

"In the region of 8 psi overpressure (Position 3), both shelters afford protection against blast pressure; but the measured nuclear radiation in the uncovered shelter of from 600 r to 800 r would have been fatal to occupants. The additional shielding afforded by the cover of spoil reduced this radiation to a range of from 80 r to 175 r, which is not considered to be a lethal dose. Protection from gamma appears to be the paramount problem in the shelter design; since, in the case of the shelters tested here, protection against blast and thermal effects apparently was greater than the protection against prompt gamma radiation.

"Soil structure is a major factor determining how well the shelter walls will withstand the effects of a blast. At Position 2, where the soil structure was fairly good, the shelter held at 18.5 psi overpressure; whereas, at Position 4, where the soil structure was poor, the sides of the shelter gave way at only 3.9 psi overpressure.

"The shape of the earth mound forming the cover should be broad and flat. The peaked mound of the covered shelter at Position 2 was greatly lowered; while the flat, low mound formed from the spoil of the uncovered shelter at that position was only slightly altered by the blast.

"Total thermal radiation estimated from observations of clothed dummies and charred wood is highly inadequate and not reliable."

It was recommended that: "If more detailed information on thermal radiation and blast effects on shelters of this type is desired, a more extensive program of instrumentation should be used in conjunction with a future test."

CHAPTER 2

EXPERIMENT DESIGN

2.1 TEST STRUCTURES

2.1.1 General Description

Fifty simplified structures were used to represent 12 command posts, 19 machine gun emplacements, and 19 two-man foxholes. All of the structures included revetment and overhead cover, the structure frames following timber bridge nomenclature and consisting of posts, caps, stringers, revetment, and top filler. The structures were varied in strength and materials for purposes of comparison. Table 2.1 shows the extent of variation of materials for each structural component. This variation is further illustrated in Tables 3.1 through 3.3, which show the particular materials used in each structure. Along with the variation in strength and materials, two types of construction were used. These consisted of the continuous-stringer type and the spaced-stringer-with-top-filler type and are illustrated in Figs. 2.1 through 2.6.

TABLE 2.1 - Variation in Materials

Component	Material
Post	8" x 8" timber 4" x 4" timber 2" x 4" timber
Cap	8" x 8" timber 4" x 4" timber 2" x 4" timber
Stringer	4" x 4" timber 2" x 4" timber 1" x 6" timber
Revetment	4" x 4" timber 1" x 6" timber 5/8" plywood corrugated iron

TABLE 2.1 - Variation in Materials (Continued)

Component	Material
Revetment(cont'd)	chicken wire and burlap chicken wire and pasteboard pasteboard
Top Filler	1" x 6" timber 5/8" plywood corrugated iron chicken wire and burlap chicken wire and pasteboard pasteboard

The construction of the command posts is shown in Figs. 2.1 and 2.2. The figures show an underground side view, with the near wall and post removed. The command posts were constructed with their stringers at grade level. The overall inside dimensions were 6 ft x 6 ft x 6 ft. The overall dimensions of the cover were 9 ft x 9 ft overlain with about 2 ft of loose earth. The entrance excavation protruded 6 ft from the wall of the structure and was 2 ft wide, with three 2 ft steps cut down to the command post proper. The sizes and spans of the timbers and the various materials used for each component in each command post are included in Table 3.1.

The construction of the machine gun emplacements is shown in Figs. 2.3 and 2.4. The figures show a partially underground rear view, with a portion of the rear wall and posts cut away. The stringers were 1½ ft above grade level, and the overall dimensions of the cover were 8½ ft x 10 ft overlain with about 1 ft of loose earth and sandbags. The overall inside dimensions were 5½ ft long x 7 ft wide x 6 ft tall. The entrance excavation protruded 6 ft from the rear wall and was 2 ft wide and 2 ft deep, leaving a 2 ft step down to the floor of the emplacement. The sizes and spans of the timbers and the various materials used for each component in each machine gun emplacement are included in Table 3.2.

The construction of the two-man foxholes is shown in Figs. 2.5 and 2.6. The figures show an underground corner view, with portions of the walls cut away. The overall inside dimensions of the foxholes were 2 ft long x 6 ft wide x 5½ ft tall. The stringers were 1 ft above grade level, and the cover had overall dimensions of 5 ft x 9 ft overlain with about ½ ft of loose earth and sandbags. On some of the foxholes, not shown, the cover had no overhang reducing the dimensions to 2 ft x 6 ft. The timber sizes and spans and the materials used in each foxhole are included in Table 3.3.

2.1.2 Instrumentation

Peak pressure measurements were made both outside and inside one command post, one machine gun emplacement, and one two-man foxhole with indenter peak pressure gages furnished by the Naval Ordnance Laboratory (NOL). This instrumentation was actually a part of the overpressure multiplication study, and the details are presented in Part II.

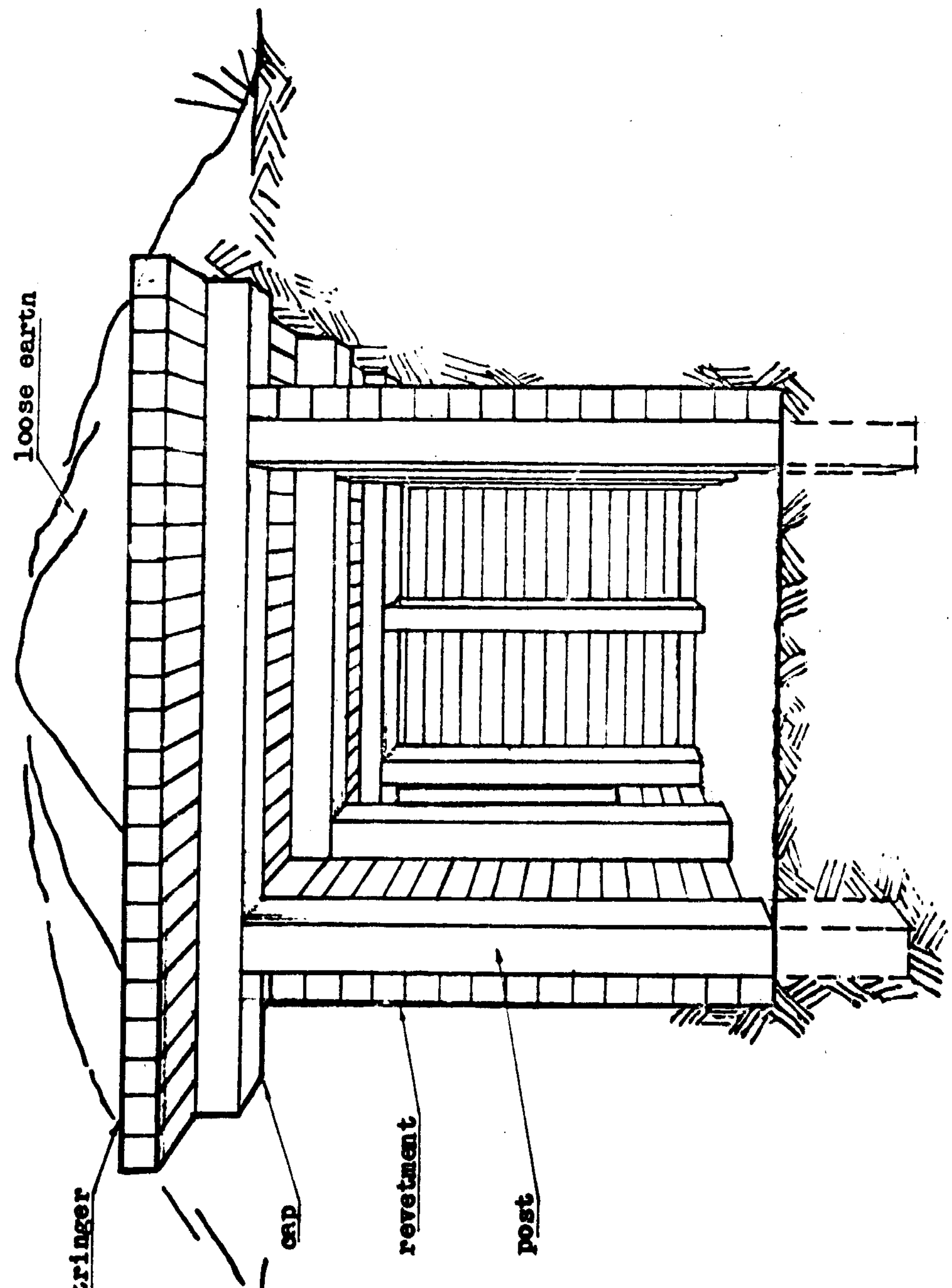


Fig. 2.1 Command Post with Continuous Stringers

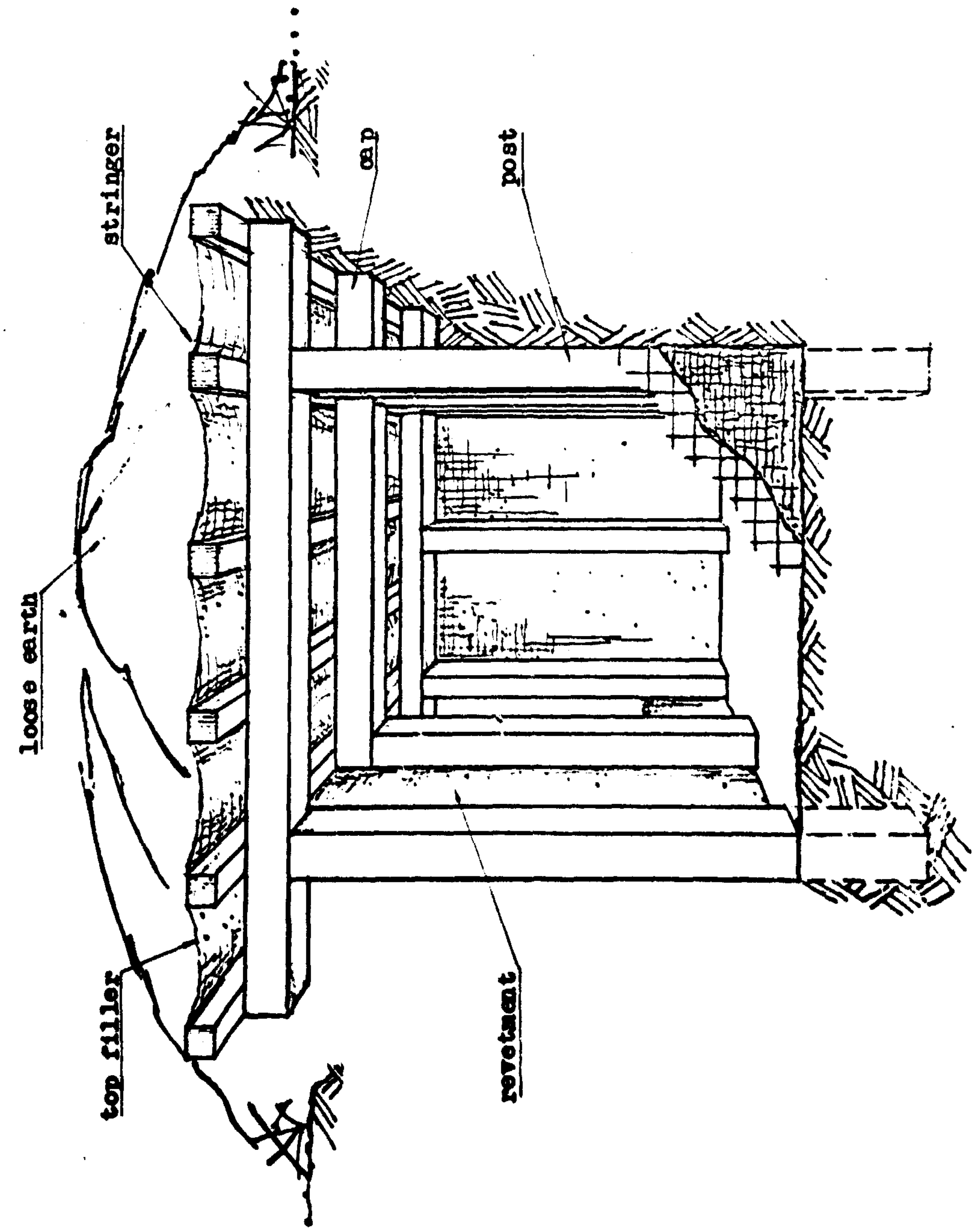


Fig. 2.2 Command Post with Spaced Stringers and Top Filler

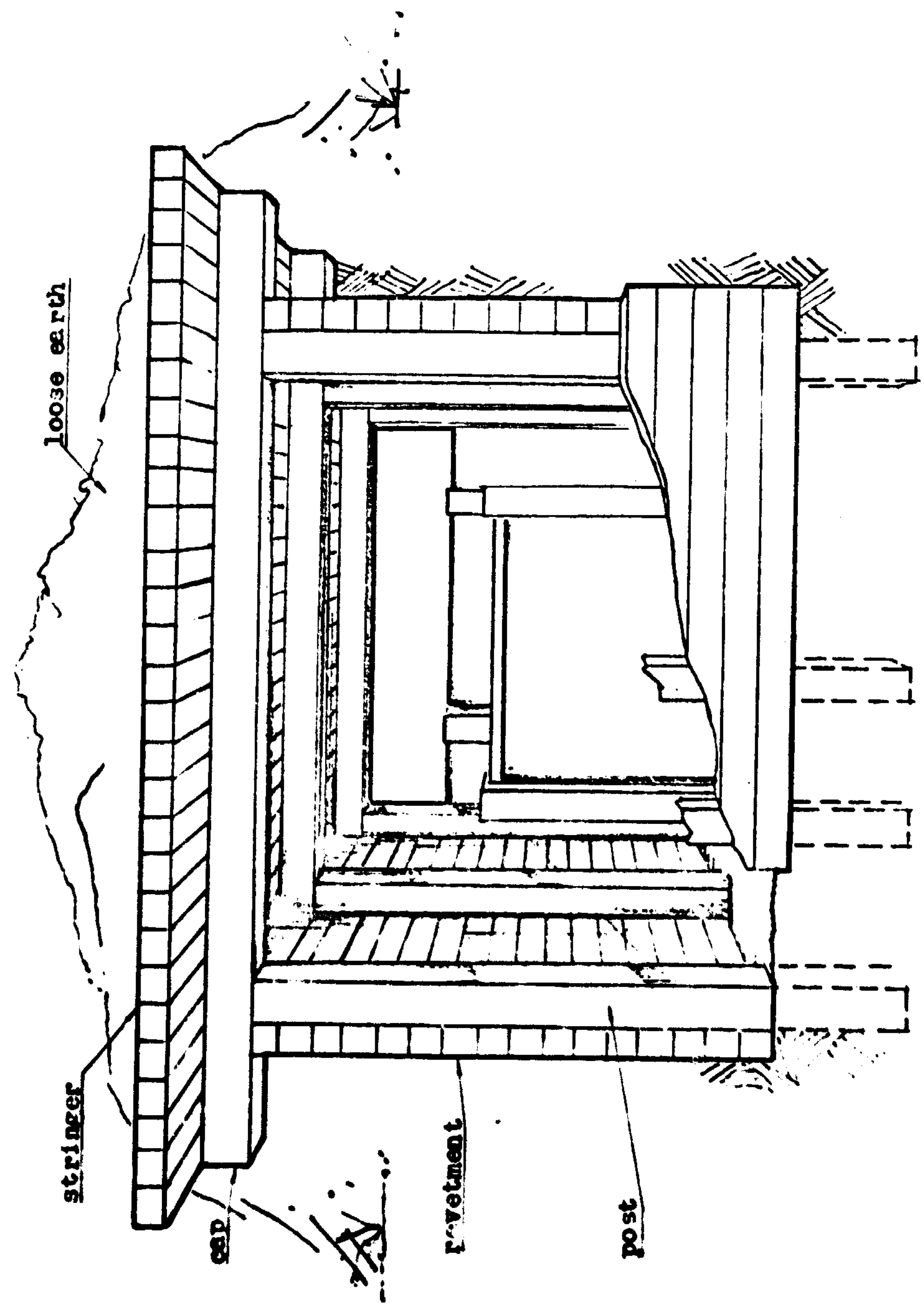


Fig. 2.3 Machine Gun Emplacement with Continuous Stringers

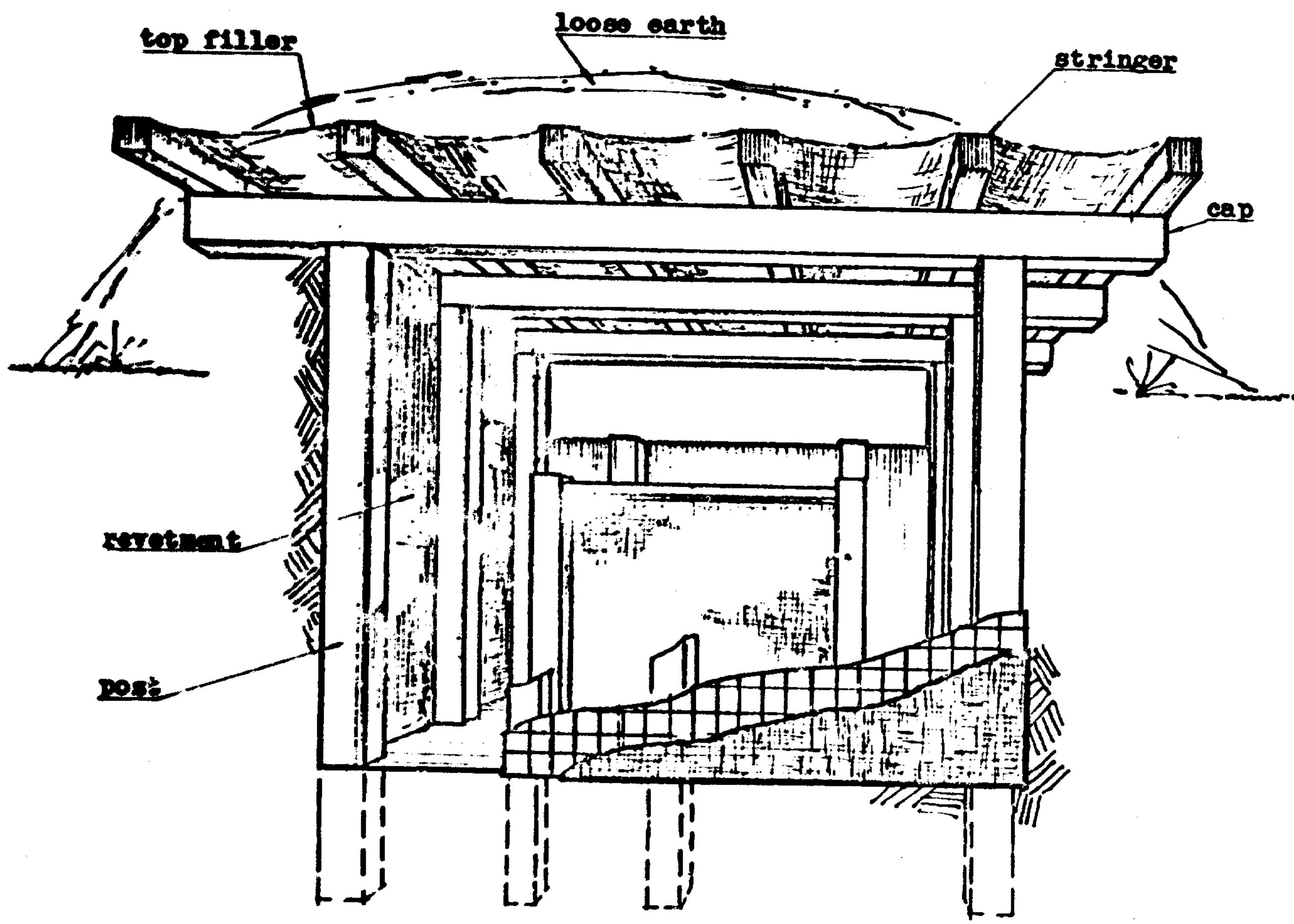


Fig. 2.4 Machine Gun Emplacement with Spaced Stringers and Top Filler

2.2 TEST PROCEDURE

2.2.1 Site Layout

The test structures were constructed by personnel from the 412th Engineer Construction Battalion. Fifty structures were divided between three areas--Area 3.9-A at 500 ft, Area 3.9-B at 1500 ft, and Area 3.9-C at 4000 ft from target ground zero. The exact location of the areas is shown in Appendix A, and the detailed distribution of the structures in each area is shown in Appendix B.

2.2.2 Shot Participation

It was anticipated that all areas would be exposed to Shot 9 and Shot 10. The plan was to rehabilitate the structures after Shot 9.

2.2.3 Recording the Effects on Structures

The effects on the test structures were recorded by preshot and postshot photography supplemented with postshot inspection notes. The photography was furnished by Program 9, AFSWP.

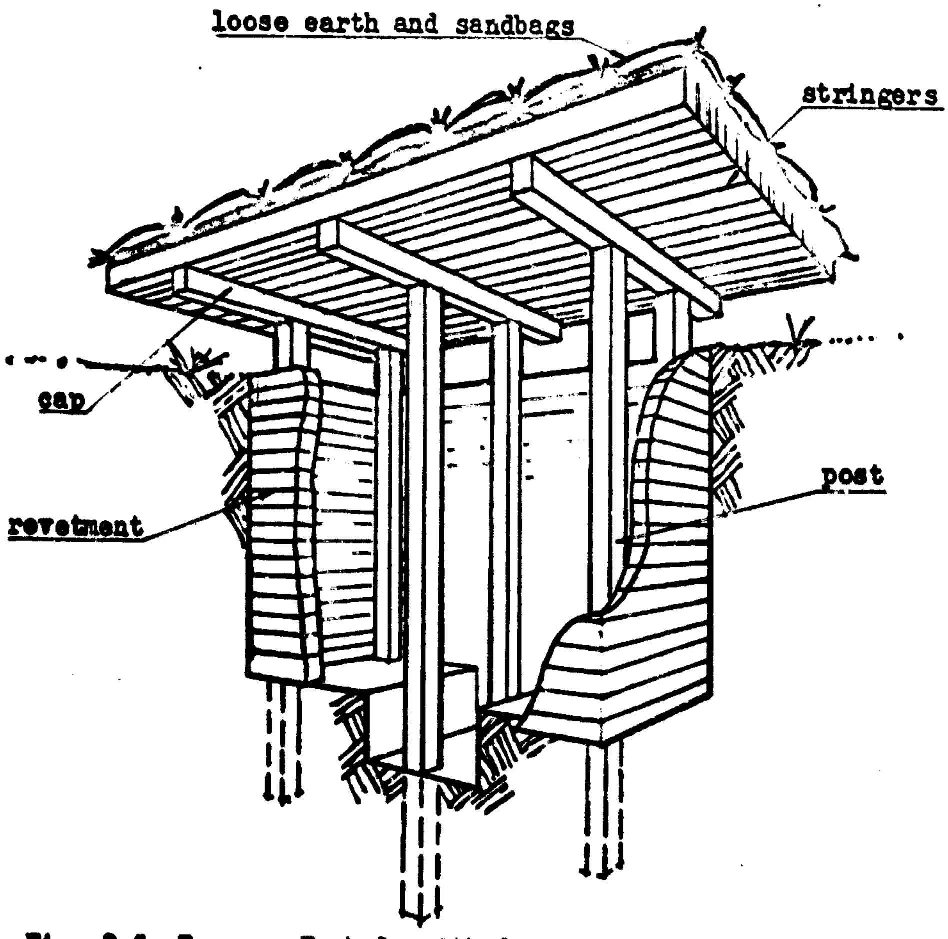


Fig. 2.5 Two-man Foxhole with Continuous Stringers

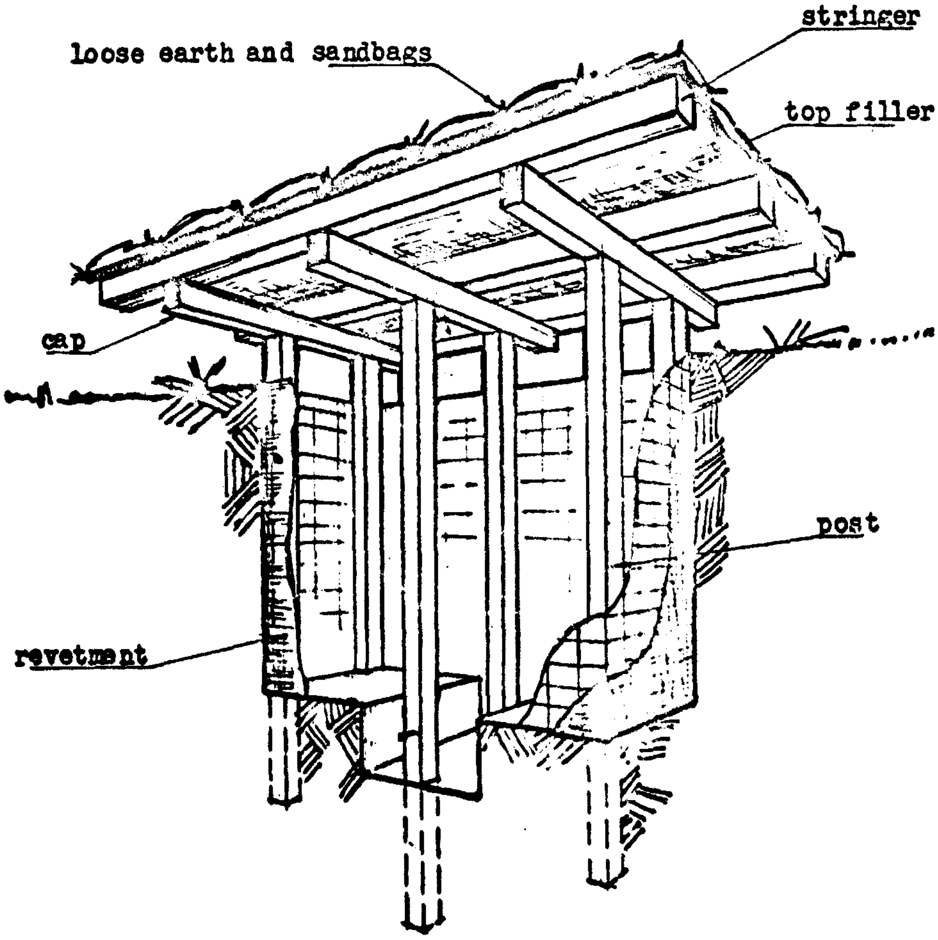


Fig. 2.6 Two-man Foxhole with Spaced Stringers and Top Filler

CHAPTER 3

RESULTS

3.1 INTRODUCTION

3.1.1 Shot Participation

Shot 9, 8 May 1953, was a 26 KT air burst at a height of 2423 ft with the actual ground zero located 837 ft south and 15 ft west of target ground zero. Shot 10, 25 May 1953, was a 14.9 KT air burst at a height of 524 ft with the actual ground zero located 139 ft south and 86 ft west of target ground zero.

All three areas were exposed to Shot 9. The actual ground zero for this shot was located between and to one side of Areas 3.9-A and 3.9-B; and, as a result, the peak overpressures and peak dynamic pressures were changed from those expected in these areas. Area 3.9-C was little affected by this miss of target ground zero.

Since the damage to the structures from Shot 9 was not severe and the 412th Engineers had a heavy work load between shots, it was decided that only Area 3.9-A be restored for Shot 10 and that Areas 3.9-B and 3.9-C be policed. The work order was interpreted by the construction personnel to mean that Areas 3.9-B and 3.9-C be removed. As a result, only Area 3.9-A was exposed to Shot 10. The miss in target ground zero for Shot 10 resulted in Area 3.9-A being about 350 ft rather than the planned 500 ft from actual ground zero. This substantially increased the expected pressures.

3.1.2 Tabulation of Effects on Structures

Tables 3.1 through 3.3 break down the effects of Shot 9 into the effects on each component of each structure. The effects of Shot 10 are not tabulated, since the damage was so complete that they are better described. The tables are explained as follows: The ranges and approximate peak overpressures are actual values, not expected values. The timber sizes are designated sizes, the actual dimensions being somewhat smaller since finished timber was used.

TABLE 3.1 - Effects on Command Posts, Shot 9

Fort. No.	Ground Range(ft)	Peak Over-Pressure (psi)	Stringers No.-Size-Span	Stringers Eval.	Caps No.-Size-Span	Caps Eval.	Posts No.-Size	Posts Eval.	Revetment & Top Filler Type	Revetment & Top Filler Eval.
1	650	25	30-4"x4"-3'	0	2-8"x8"-3' 1-8"x8"-6'	0 0	8-8"x8"	0	4"x4"	0
2	620	25	30-4"x4"-3'	0	2-8"x8"-3' 1-8"x8"-6'	0 0	8-8"x8"	0	4"x4"	0
3	590	25	30-4"x4"-3'	0	2-8"x8"-3' 1-8"x8"-6'	0 0	8-8"x8"	0	4"x4"	0
4	560	25	5-4"x4"-3' 1-4"x4"-3'	0 S	2-4"x4"-3' 1-4"x4"-6'	S M	8-4"x4"	0	Cor.I.	00
18	700	23	4-4"x4"-3' 2-4"x4"-3'	0 M	2-4"x4"-3' 1-4"x4"-6'	0 X	8-4"x4"	0	Cor.I.	00
19	700	23	4-4"x4"-3' 2-4"x4"-3'	0 M	2-4"x4"-3' 1-4"x4"-6'	0 M	8-4"x4"	0	Cor.I.	00
20	700	23	5-4"x4"-3' 1-4"x4"-3'	0 M	2-4"x4"-3' 1-4"x4"-6'	0 M	7-4"x4" 1-4"x4"	0 S	Plyd.	00
21	700	23	3-4"x4"-3' 1-4"x4"-3'	0 M	2-4"x4"-3' 1-4"x4"-6'	0 X	8-4"x4"	0	CW&B	00
22	750	23	4-4"x4"-3' 2-4"x4"-3'	0 M	2-4"x4"-3' 1-4"x4"-6'	0 M	8-4"x4"	0	1"x6"	00
35	3890	8	6-4"x4"-3'	0	2-4"x4"-3' 1-4"x4"-6'	0 0	8-4"x4"	0	CW&B	00
36	3890	8	6-4"x4"-3'	0	2-4"x4"-3' 1-4"x4"-6'	0 0	8-4"x4"	0	1"x6"	00
37	3890	8	4-4"x4"-3' 1-4"x4"-3'	0 X	2-4"x4"-3' 1-4"x4"-6'	0 X	8-4"x4"	0	CW&B	00

0 - undamaged; S - slightly damaged or cracked; M - moderately damaged or cracked and bent;
X - severely damaged or broken.

TABLE 3.2 - Effects on Machine Gun Emplacements, Shot 9

Fort. No.	Ground Range(ft)	Peak Over-pressure (psi)	Stringers		Caps		Posts		Revetment & Top Filler	
			No.-Size-Span	Eval.	No.-Size-Span	Eval.	No.-Size	Eval.	Type	Eval.
5	650	25	30-4"x4"-2½'	0	1-8"x8"-3½' 2-8"x8"-7'	0 0	7-8"x8"	0	4"x4"	00
6	620	25	30-4"x4"-2½'	0	1-8"x8"-3½' 2-8"x8"-7'	0 0	7-8"x8"	0	4"x4"	00
7	590	25	30-4"x4"-2½'	0	1-8"x8"-3½' 2-8"x8"-7'	0 0	7-8"x8"	0	4"x4"	00
8	560	25	30-4"x4"-2½'	0	1-8"x8"-3½' 2-8"x8"-7'	0 0	7-8"x8"	0	4"x4"	00
9	650	25	30-4"x4"-2½'	0	1-4"x4"-3½' 2-4"x4"-7'	0 0	8-4"x4"	0	4"x4"	00
10	620	25	5-4"x4"-2½'	0	1-4"x4"-3½' 2-4"x4"-7'	0 X	8-4"x4"	0	Cor.I.	MO
11	590	25	5-4"x4"-2½'	0	1-4"x4"-3½' 2-4"x4"-7'	0 S	8-4"x4"	0	Plywd.	00
23	750	23	30-4"x4"-2½'	0	1-4"x4"-3½' 3-4"x4"-7'	0 X	8-4"x4"	0	4"x4"	00
24	750	23	5-4"x4"-2½'	0	1-4"x4"-3½' 2-4"x4"-7'	0	8-4"x4"	0	Cor.I.	MO
25	750	23	5-4"x4"-2½'	0	1-4"x4"-3½' 2-4"x4"-7'	0 X	8-4"x4"	0	Plywd.	00
26	800	23	7-4"x4"-2½'	0	1-4"x4"-3½' 2-4"x4"-7'	0 0	7-4"x4"	0	CW&B	SX
27	800	23	7-4"x4"-2½'	0	1-4"x4"-3½' 2-4"x4"-7'	0 X	7-4"x4"	0	CW&B	MS
28	800	23	7-4"x4"-2½'	0	1-4"x4"-3½' 2-4"x4"-7'	0 0	8-4"x4"	0	CW&B	MM
29	800	23	24-1"x6"-2½'	0	1-4"x4"-3½' 2-4"x4"-7'	0 X	8-4"x4"	0	1"x6"	00

TABLE 3.2 - Effects on Machine Gun Emplacements, Shot 9(Continued)

Fort. No.	Ground Range(ft)	Peak Over-pressure (psi)	Stringers		Caps		Posts		Revetment & Top Filler	
			No.-Size-Span	Eval.	No.-Size-Span	Eval.	No.-Size	Eval.	Type	Eval.
34	3890	8	5-4"x4"-2½'	0	1-4"x4"-3½' 2-4"x4"-7'	0 0	8-4"x4"	0	CW&B	OX
38	3940	8	5-4"x4"-2½'	0	1-4"x4"-3½' 2-4"x4"-7'	0 0	8-4"x4"	0	CW&B	OM
39	3940	8	5-4"x4"-2½'	0	1-4"x4"-3½' 2-4"x4"-7'	0 0	8-4"x4"	0	CW&B	OM
40	3940	8	4-4"x4"-2½' 1-4"x4"-2½'	0 M	1-4"x4"-3½' 2-4"x4"-7'	0 X	8-4"x4"	0	CW&B	00
41	3940	8	20-1"x6"-2½'	0	1-4"x4"-3½' 2-4"x4"-7'	0 0	8-4"x4"	0	1"x6"	00

0 - undamaged; S - slightly damaged or cracked; M - moderately damaged or cracked and bent;
X - severely damaged or broken.

TABLE 3.3 - Effects on Two-Man Foxholes, Shot 9

Fort. No.	Ground Range (ft)	Peak Over-pressure (psi)	Stringers No.-Size-Span	Stringers Eval.	Caps No.-Size-Span	Caps Eval.	Posts No.-Size	Posts Eval.	Revetment & Top Filler Type	Revetment & Top Filler Eval.
12	560	25	3-4"x4"-3'	0	3-4"x4"-2'	0	6-4"x4"	0	4"x4"	0,0
13	650	25	3-4"x4"-3'	0	3-4"x4"-2'	0	6-4"x4"	0	4"x4"	0,0
14	650	25	2-4"x4"-3'	0	3-4"x4"-2'	0	6-4"x4"	0	4"x4"	0,0
15	620	25	3-4"x4"-3'	0	3-4"x4"-2'	0	6-4"x4"	0	1"x6"	0,0
16	590	25	3-4"x4"-3'	0	3-4"x4"-2'	0	6-4"x4"	0	4"x4"	0,0
17	620	25	3-2"x4"-3'	0	3-2"x4"-2'	0	6-2"x4"	0	CW&PB	0,0
30	850	23	14-4"x4"-3'	0	3-4"x4"-2'	0	6-4"x4"	0	Plywd.	0
31	850	23	4-2"x4"-3'	0	3-2"x4"-2'	0	6-4"x4"	0	CW&B	S,0
32	850	23	4-2"x4"-3'	0	3-2"x4"-2'	0	6-2"x4"	0	CW&PB	M,0
33	850	23	16-2"x4"-3'	0	3-2"x4"-2'	0	6-2"x4"	0	1"x6"	0
42	3990	8	3-4"x4"-3'	0	3-4"x4"-2'	0	6-4"x4"	0	CW&B	0,0
43	3990	8	2-4"x4"-3'	0	3-4"x4"-2'	0	6-4"x4"	0	CW&B	0,0
44	3990	8	3-2"x4"-3'	0	3-2"x4"-2'	0	6-2"x4"	0	P.Bd.	0,X
45	3990	8	3-2"x4"-3'	M	3-2"x4"-2'	0	6-2"x4"	0	CW&PB	0,S
46	4040	8	3-2"x4"-3'	0	3-2"x4"-2'	0	6-2"x4"	0	CW&PB	0,X
47	4040	8	3-2"x4"-3'	0	3-2"x4"-2'	0	6-2"x4"	0	1"x6"	0,0
48	4040	8	3-4"x4"-3'	0	3-4"x4"-2'	0	6-4"x4"	0	CW&B	0,0
49	4040	8	3-2"x4"-3'	0	3-2"x4"-2'	0	6-2"x4"	0	CW&PB	0,S
50	4070	8	3-2"x4"-3'	0	3-2"x4"-2'	0	6-2"x4"	0	1"x6"	0,0

0 - undamaged; S - slightly damaged or cracked; M - moderately damaged or cracked and bent;
X - severely damaged or broken.

3.1.3 Photography

Preshot and postshot photographs of all test structures for both Shot 9 and Shot 10 are presented in Appendix C. The photographs are considered important because they constitute the only real and impartial record of the test. All of the damaged elements in any emplacement are shown in the photographs.

3.2 EFFECTS ON COMMAND POSTS

3.2.1 Effects of Shot 9

As shown in Table 3.1, most of the damage was confined to the failure of the center 4" x 4" caps and stringers at midspan. The evaluation of the damage to top fillers in the table does not take into consideration that small portion covering 4 ft of the entranceway. In general, the entrances were about half filled with loose earth; and the top filler immediately over the entrance was crushed inward enough to make access to the fortification difficult. It appeared that some of the loose earth mound covering the fortifications was removed by the blast. In most cases, the volume of the mounds was reduced by about one-fifth.

3.2.2 Effects of Shot 10

The peak overpressure in Area 3.9-A was approximately 300 psi, extrapolated value. All of the command posts were severely damaged. About one-fourth of the 8" x 8" posts failed in compression; most of the posts were displaced, and some appeared to have been driven slightly into the ground. The center 8" x 8" caps were broken and the two end caps severely shattered, showing 1 in. deep impressions where they had rested on the posts. About one-half of the 4" x 4" stringers were broken, the remainder suffering no apparent damage other than being removed from position. It appeared that the covers had been partly blown down into the fortifications and partly scattered about the area. Even though there were many undamaged timbers, all of the cover timbers were separated, no cover remaining even partly intact. The fortification excavations were about half filled with loose earth and rubble. The 4" x 4" timber revetments were bowed in, but the timbers retained their same relative positions and were not damaged. One command post of relatively light construction, 4" x 4" timbers and corrugated iron, was completely destroyed.

3.3 EFFECTS ON MACHINE GUN EMPLACEMENTS

3.3.1 Effects of Shot 9

As shown in Table 3.2, most of the damage to structural members was confined to the failure at midspan of the two front 4" x 4" caps. The evaluation of the damage to revetments and top fillers is problematic, because the damage seemed to be as attributable to poor construction as to lack of strength in the materials. In Area 3.9-A where the

peak dynamic pressure was about 0.7 psi, most of the loose earth and sandbags covering emplacements remained in place and there was little damage to revetments and top fillers, which were strongly constructed. In Area 3.9-B where the peak dynamic pressure was about 0.9 psi, the revetments and top fillers of emplacements utilizing chicken wire and burlap were damaged and the loose earth and sandbags covering these emplacements were half removed. In Area 3.9-C where the peak dynamic pressure was about 1.6 psi, the top fillers of emplacements utilizing chicken wire and burlap were damaged and the burlap, loose earth, and sandbags covering these emplacements were almost totally removed. In one case in this area, the entire cover, including 4" x 4" stringers and 1" x 6" top filler, was moved intact about 4 ft toward ground zero. The entrance excavations in all three areas were about half filled with displaced and ruptured sandbags and loose earth.

3.3.2 Effects of Shot 10

The three emplacements having 4" x 4" timber structural frames were destroyed beyond recognition. The four emplacements utilizing 8" x 8" timbers for posts and caps and 4" x 4" timbers for stringers and revetment were destroyed but still recognizable. Confining the discussion to the latter four emplacements, a few useful observations can be made. The superstructures were entirely removed, leaving the excavations almost filled with scrambled timbers, loose earth, and rubble. A few of the 8" x 8" posts remained undamaged; and, where the posts had remained, the 4" x 4" timber revetments were relatively undamaged and in position. The walls of the emplacements were pushed inward, reducing the dimensions somewhat below the original dimensions. There were a multitude of undamaged 4" x 4" timbers strewn in and about the emplacements, some of which must have been stringers and others part of the revetments. It appeared that if the posts had held, the 4" x 4" timber revetments would have held also. In general, damage to the machine gun emplacements was more severe than the damage to command posts of the same timber size construction.

3.4 EFFECTS ON TWO-MAN FOXHOLES

3.4.1 Effects of Shot 9

As shown in Table 3.3, there was no appreciable damage to the individual structural members of the foxholes. In Areas 3.9-A and 3.9-B, there was little damage to top fillers and most of the loose earth and sandbags covering the foxholes remained in place. In these areas, a few of the 2" x 4" posts were driven farther into the ground, allowing the covers to slant. In Area 3.9-C, the foxholes having the more substantial revetments and top filler, 1" x 6" lumber, suffered no damage other than the removal of loose earth and sandbags. Foxholes with lighter revetments and top filler, chicken wire and burlap or pasteboard, suffered considerable derangement of their superstructure. In some cases, the timbers forming the cover were pulled apart at their joints; and, in other cases, the whole cover frame was displaced, pulling the posts out of position. The top filler materials, sandbags, and loose earth were

removed. In general, the earth walls of the foxholes would have held even if they had not been revetted.

3.4.2 Effects of Shot 10

The only thing that remained of the foxholes was the 4" x 4" revetment timbers and a few 4" x 4" posts. Most of the foxholes were completely filled in, but two were still open enough to indicate the process of failure. It appeared that the two 6 ft walls had been moved inward uniformly, reducing the original 2 ft dimension of the foxholes to about 8 in. in these two cases and completely closing the foxholes in all other cases. Other than this, the revetment timbers of the two partially open foxholes were relatively undamaged and retained their same relative position.

3.5 GENERAL OBSERVATIONS

3.5.1 Gross Effects of Thermal Radiation

The incident thermal energies in the areas varied from 40 to 160 cal/cm^2 for Shot 9. All of the exposed sandbags were burned and had spilled their contents. In many instances, this loose earth was spilled into the entrances of the test structures. Only a few timbers were burned severely, and there were no significant fires continuing after the shock wave had passed. Of some significance was the heavy scorching of the underneath side of burlap top filler and the inside of chicken wire and burlap revetted back walls of the machine gun emplacements in Area 3.9-B. The foxholes utilizing chicken wire and burlap were similarly damaged.

3.5.2 Joints and Fastenings of Structure Components

Foxholes and machine gun emplacements experienced forces from the high winds which resulted in the removal or dislocation of various members and parts. Individual timbers were not damaged, but only disjoined. Because of the structure design, the quality of workmanship going into the joints and fastenings largely determined the extent to which a particular emplacement was damaged.

CHAPTER 4

DISCUSSION

4.1 OVERHEAD COVER

4.1.1 Test Results, Shot 9

The structural damage done to command post cover was a result of the action of the blast induced air pressure difference between the top and bottom sides of the cover, hereafter called diffraction type loading for brevity. In seven of the nine command posts having 4" x 4" caps and stringers, the center cap failed in bending at midspan, increasing the span for stringers which then failed. Estimating the time required for the average pressure within the command post to reach its effective peak to be in excess of 90 msec(10), and considering that within the one instrumented command post the maximum peak overpressure measured was 0.7 as great as that measured outside at ground level, it can be seen that there was a significant pressure differential between the top and underside of the cover. Since there was no serious damage to the top fillers or 4" x 4" posts, and there was evidence that the stringers failed only as a result of cap failure, the center cap proved to be the limiting member in the structure.

Structural damage to machine gun emplacement covers was in part a result of diffraction-type loading. In 6 of 15 emplacements having 4" x 4" caps, the center and front cap failed in bending at midspan. On a percentage basis, only half as many machine gun emplacements as command posts suffered cap failure. Coupling this observation with the fact that the maximum peak overpressure measured within the machine gun emplacement was twice that measured within the command post, one would suspect that the machine gun emplacement cover was subjected to a lighter load because of the relieving pressure reaching a significant value in a shorter time. However, when all factors are considered, including the short response time of the timbers, the implication is not certain when based on this test alone. Since there was no other serious damage to the machine gun emplacement cover resulting from diffraction-type loading, the center and front cap proved to be the limiting members in the structure.

Other than a few instances of posts being driven slightly farther into the ground, showing that there was a definite downward push on the cover, there was little evidence of diffraction loading on foxhole covers.

The maximum peak overpressure measured inside the instrumented foxhole was about the same as that measured outside at ground level.

Although the dynamic pressures (wind pressures) were small, 0.7 to 1.6 psi, their effect on cover was in evidence. For the command posts, the damage was limited to the removal of part of the loose earth cover; whereas, for machine gun emplacements and foxholes, whose cover structure was above grade level, the effects were multiple. Generally speaking, the dynamic pressures were effective in tearing the cover materials apart from each other where they were joined, blowing away the loose materials, and moving whole covers or parts thereof out of position. The effects were most severe on those emplacements having chicken wire and burlap top filler.

The gross effect of thermal radiation on the cover structure of the fortifications was not severe. An examination of the test structures showed that there was no serious fire hazard and that the few fires that had been started were either blown out or left in a smouldering state by the blast. All of the exposed sandbags were severely burned and ruptured, and were of little value for holding loose earth in place. The sandbags having a small amount of earth covering them were not damaged. Examination of the covers to machine gun emplacements and foxholes showed that thermal radiation had reflected from the ground and scorched the underneath side of the burlap used in chicken wire and burlap top filler. This was particularly noticeable because of the design left on the burlap by the shielding effect of the chicken wire. No threshold values for thermal radiation effects on the materials are available from this test.

4.1.2 Test Results, Shot 10

Of all parts of the fortifications that had originally been above natural grade level, little or nothing remained in place. The covers to machine gun emplacements and foxholes could not be identified after the shot. Although the covers to command posts stood up better than the others, none remained intact; and the manner of failure was at best a matter of conjecture. It appeared that the 8" x 8" center caps had failed first in horizontal shear then in bending at midspan, and that the end caps had failed in horizontal shear only with a beginning failure in either bending or vertical shear. About one-fourth of the 8" x 8" timber posts failed in compression, a few were driven slightly farther into the ground, and most were left leaning inward to some degree. The large number of scattered and undamaged 4" x 4" timbers showed the inadequacy of designing for conventional forces.

4.1.3 Generalization of Past Results

The following generalizations applicable to overhead cover can be made from the results and conclusions of past tests:

Damage to structures is less severe when they are covered by even a small amount of earth. Wood shelters offer good resistance to blast provided they are properly protected with earth cover. They do not burn, and their resiliency permits them to absorb considerable shock without failing completely. As the elevation of a shelter is increased

with respect to natural grade level, larger amounts of earth cover are subject to removal; and there is a reduction in the shelter's resistance to blast, as well as increase in the measured gamma radiation doses.

The covered shelter affords greater protection against atomic effects, particularly gamma radiation, than does the uncovered shelter. For air bursts, overhead cover greatly reduces the gamma radiation doses within fortifications; whereas, for surface bursts, the reduction directly attributable to overhead cover is less. The first limit in the protection afforded by covered shelters has been gamma radiation.

Although the gold neutron flux does not decrease appreciably with depth in an open fortification, there is a marked decrease in fortifications having a concrete cover. Sulphur neutron flux does decrease with depth in open fortifications and is further reduced in fortifications having a concrete cover.

4.1.4 Generalization of the Present Results

The following generalizations can be made from the observation of the effects on overhead cover in this test:

Fortification covers located flush with grade level are primarily damaged by diffraction-type loading. When located above grade level, cover components may be seriously disarranged by the dynamic pressure; however, the physical breaking of timbers and materials themselves is still a result of diffraction loading on the cover. Disarrangement begins to appear at dynamic pressures as low as 0.7 to 1.6 psi, and is dependent upon the design and the quality of workmanship going into the joints and fastenings.

For both above and below grade covered fortifications, the longer spanned, horizontal supporting members limit the strength of the cover's resistance to diffraction loads. The posts supporting these caps are relatively invulnerable to damage from loads on the cover; and, if the soil is at all stable, they are better sunk into the soil than set on timber footings or spreaders. Light top filler materials, such as chicken wire and burlap or pasteboard, corrugated iron, 5/8" plywood, and 1" x 6" lumber, when supported at about 2½ ft intervals and covered with loose earth, are not seriously damaged by the diffraction load on the cover at a peak overpressure of 25 psi.

There is no serious fire hazard created by using timbers and other lighter materials in fortifications. The primary damage from thermal radiation is the burning of directly exposed sandbags. Those sandbags covered with small amounts of loose earth are not damaged.

4.2 REVETMENT

4.2.1 Test Results, Shot 9

The revetments were constructed with a few inches of very loose, fine earth backfill between them and the solid earth walls. Although this loose material may have acted as a buffer, the effect was not apparent.

Generally speaking, all kinds of revetments held up well, there being no failure directly attributable to a lack of strength in the

materials themselves. The chicken wire and burlap, chicken wire and pasteboard, and corrugated iron revetments showed a tendency to bulge inward, but not rupture. There were several instances in which these types of revetments pulled loose from their supporting timbers; however, in each instance, examination showed that they had not been well attached. The plywood revetments did not bulge inward as much as the others and were affected less by the quality of workmanship. The 1"x6" and 4"x4" timber revetments were not damaged at all by the blast. Considering general strength, simplicity of quality construction, and dependability, the 1"x6" and 4"x4" timber revetments proved to be superior to other types.

While the lighter materials were successfully used for the revetment of the main walls of the fortifications, they proved to be unsatisfactory, and in some cases hazardous, when used as revetment for the gun mount platforms in the machine gun emplacements. Only the 1"x6" and 4"x 4" timber revetments held these earth platforms in place satisfactorily.

4.2.2 Test Results, Shot 10

All revetments except those constructed from 4"x4" timbers failed completely. The 4"x4" timber revetments were supported by posts at about 3 ft intervals which yielded to varying degrees to the lateral earth forces. Although the 4"x4" revetment timbers bowed in accordingly, they did not break; and each wall remained intact. It appeared that had the posts remained rigid and unmoved, the 4"x4" timber revetments would have held satisfactorily.

4.2.3 Generalization of Past Results

There is little information available from past tests on the reaction of various types of revetment to an atomic explosion. It has been generally concluded that all normal types of revetment are adequate for military use, that revetments permit fortifications to hold up at much closer distances to ground zero than do the unrevetted fortifications, and that soil structure is a major factor determining how well unrevetted walls will withstand a blast. One-inch lumber and chicken wire and tarpaper revetments have been used successfully at ranges where the peak air overpressure was about 15 psi.

4.2.4 Generalization of the Present Results

Diaphragm type revetments such as those constructed from chicken wire and burlap, chicken wire and pasteboard, corrugated iron, and plywood may be successfully used at ranges from air bursts where the peak air overpressures are about 25 psi provided that care is taken to attach them well to supports spaced about 2½ ft apart and provided that they are not depended upon to add strength or stability to the overall basic structure.

Considering general strength, simplicity of quality construction, and dependability, the 1"x6" and 4"x4" timber revetments are superior to the others. Rigidly supported at about 3 ft intervals, a 4"x4" timber revetment appears to have sufficient strength to stand up at a range from

an air burst where the peak air overpressure is of the order of 300 psi.

4.3 ENTRANCES AND APERTURES

4.3.1 Results

The entrances to the machine gun emplacements and command posts used in this test were purposely kept simple and direct. More elaborate entrance construction would not have added much to the value of the overall test; because, structurally, entrances fall within the revetment and overhead cover study and otherwise are tied in with protection from physiological effects. Although simple and unrevetted, the entrances used in this test did lend weight to various observations made in the tests summarized in Chapter 1. To save repetition, generalizations of the effects on entrances are not presented here but are incorporated into the discussion in the following section in that they substantiate the emphasis placed on some of the past observations.

The machine gun emplacements were constructed such that there was no chance of direct thermal radiation entering the firing aperture in Area 3.9-B. However, the thermal radiation entering this aperture after reflecting from the ground in front of the emplacements was of sufficient intensity to burn burlap on the back walls inside the fortifications.

4.3.2 Generalization of Past Results

The entrance construction of most structures has been considerably weaker than the structure proper and has been almost invariably the limiting factor in blast resistance.

Scorching of parts of entrances not directly exposed to thermal radiation has indicated reflection of some magnitude; however, those entrances requiring reflections of thermal radiation to enter the structure proper have successfully shielded the interior from high values of thermal radiation.

Directly exposed sandbags burn and rupture, spilling their contents. The use of such sandbags adjacent to entrances has invariably resulted in the partial filling of the entrances with loose earth and damaged sandbags.

Cutting an entrance into a covered fortification can remove a great deal of the earth shielding against gamma radiation and can greatly reduce the nuclear radiation protection otherwise offered by the addition of overhead cover.

4.4 GENERAL OBSERVATIONS

The importance of proper design and high quality construction is highly magnified by the nature of the forces resulting from an atomic explosion; and, if the construction plans for a structure do not adequately present all detail, improvisations on the part of the constructors are not likely to be in favor of the structure's resistance to atomic effects.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The following conclusions represent a consolidation of the more certain observations made in past reports with those made in this test. Conclusions concerning damage probability are presented in Appendix G.

5.1.1 Overhead Cover

The covered shelter affords greater protection against atomic effects, particularly nuclear radiation, than does the uncovered shelter. For air bursts, overhead cover greatly reduces gamma radiation doses within fortifications; whereas, for surface and subsurface bursts, the reduction directly attributable to overhead cover is less. In general, the lethal radius of nuclear radiation has been greater than the lethal radius of other effects in both open foxholes and covered shelters.

As the elevation of the cover is increased with respect to the natural grade level, large and increasing amounts of loose earth are subject to removal; and there may result an appreciable increase in the measured gamma doses within the structure, since in many situations the blast wave passes before all of the nuclear radiation is absorbed.

The effect of blast on overhead cover construction depends upon, among other things, the structure's elevation with respect to natural grade level. Fortifications that have their total profile flush with grade level are subject to loads which tend to rupture the longer spans of the horizontal supporting members by pushing downward on the cover; whereas, those fortifications having their cover structure above grade level are not only subject to this diffraction load but are also subject to drag type loads which tend to disarrange and remove entire cover structures or parts thereof.

Light top filler materials such as chicken wire and burlap or pasteboard, corrugated iron, plywood, and 1 in. lumber, when supported at about 2½ ft centers and covered with loose earth, are sufficiently strong to withstand diffraction loads on the cover to fortifications at a peak overpressure of 25 psi. However, as pointed out above, the members acting as supports for these materials are subject to failure.

Posts used to support the cover are relatively invulnerable to damage and, if the soil is at all stable, are better sunk into the soil than set on footings or spreaders.

Overhead cover structure suffers less damage from diffraction loads when covered with earth. Although the exact physical nature of the phenomenon has yet to be resolved, it can be stated generally that earth effectively adds mass to supporting members, increasing the time of response to impact loads; and, if of substantial thickness, it effectively absorbs some of the energy of the blast wave. The results of a recent study of earth cover should be consulted when they become available (11).

5.1.2 Revetment

Because of the unknown nature of the transmission of a shock wave through earth and of the loading of structures by such a wave, required revetment strength is based more on experience than theoretical calculation. Soil structure has been a major factor determining how well unrevetted walls withstand a blast; however, it has not yet been shown to affect success of revetted walls. In general, the forces applied to revetments have been considerably less effective than those applied to cover structure by a blast, and relatively light revetment construction has been successful.

Light filler materials, such as chicken wire and burlap or pasteboard, corrugated iron, and plywood, when supported at about $2\frac{1}{2}$ ft intervals, are sufficiently strong for revetting purposes at ranges where the peak air overpressure is 25 psi. However, they cannot be depended upon to add strength or stability to the overall structure; and they are subject to failure resulting from a lack of quality workmanship on the ties between them and their supporting structure. Considering general strength, simplicity of construction, and dependability, these materials are inferior to 1"x6" and 4"x4" timber.

5.1.3 Entrances and Apertures

The protection from nuclear radiation afforded by covered fortifications can be reduced by entrances and other apertures. By removing part of an earth wall, an entrance can remove a great deal of the earth normally shielding against nuclear radiation, and thus substantially depreciate the additional nuclear radiation protection otherwise offered by the use of overhead cover. The inclusion of firing apertures necessitates that a covered fortification be partially above grade and complicates the problem of obtaining effective earth cover.

Scorching of parts of fortifications not directly exposed to thermal radiation has indicated reflections of some magnitude. However, by constructing entrances to require at least two reflections of thermal radiation to enter the structure proper, the interior of a fortification can be successfully shielded from high values of thermal radiation.

The use of directly exposed sandbags adjacent to entrances results in the partial filling of the entrances with loose earth spilled from burned sandbags.

There is a tendency to slight the design and construction of

entrances. Aside from nuclear and thermal radiation considerations, entrance construction has been generally the weakest point of blast resistance in past tests. Structurally, entrances fall within the revetment and overhead cover study, and their proper construction is as important as that of any other part of a fortification.

5.1.4 General

There is no serious fire hazard created by using timber and other lighter materials in fortifications. The primary damage from thermal radiation is the burning of exposed sandbags, which are then of no value for holding their contents in place. Those sandbags covered with small amounts of loose earth are not damaged.

The importance of proper design and high quality construction are highly magnified by the nature of the forces resulting from an atomic explosion; and, if the construction plans for a structure do not adequately present all detail in a simple and direct manner, improvisations on the part of the constructors are not likely to be in favor of the structure's resistance to atomic effects.

Although large quantities of field fortifications have been subjected to atomic exposions, most of these were part of the DESERT ROCK Exercises, whose mission did not include obtaining detailed effects information but was pointed toward troop indoctrination and orientation. Practically all of the certain quantitative measurements made inside fortifications in the past are confined to gamma radiation--most other instrumentation being either unsuccessful or non-existent.

5.2 RECOMMENDATIONS

That the information presented in this report be included in appropriate field manuals for use in reducing the vulnerability of field fortifications to the effects of atomic weapons.

That no future tests be conducted on standard (FM 5-15) field fortifications for the purpose of obtaining qualitative information on their vulnerability to atomic weapon effects.

That balanced fortification designs be made by competent personnel who are familiar with the nature of the forces and radiation phenomena resulting from an atomic weapon detonation. As used here, "balanced fortification design" is intended to imply a design which reaches its limits in protection from all atomic effects, including structural failure of all parts of the fortification itself, at approximately the same range from the explosion, and in which there is a weighted compromise between atomic protection, conventional weapons protection, and practical military requirements such as drainage, limited materials, and simplicity of construction.

That, in the event suitable balanced designs are evolved, acceptance of these improved fortifications be held subject to final testing. That, in testing these finished designs, the construction of the test fortifications be closely supervised by those who are to analyze the results, that their interior be well instrumented for air pressure, gamma radiation, neutron flux, and thermal radiation, and that they be located at such distances from the explosion that their actual limit in structural strength and protection from atomic effects is realized.

PART II

PRESSURE MEASUREMENTS IN FIELD FORTIFICATIONS

CHAPTER 6

INTRODUCTION

6.1 OBJECTIVES

The objectives of Part II of Project 3.9 were as follows:

1. To determine the magnitude of overpressure build-up within open two-man foxholes, a command post, a machine gun emplacement, and a covered foxhole.
2. To observe the pressure-time characteristics of the blast wave within two-man foxholes such that a preliminary understanding of the method of the overpressure build-up is achieved.
3. To discuss the variables that were observed affecting the overpressure build-up in emplacements.

6.2 BACKGROUND

The reflection characteristics of pressure waves incident on plane surfaces have been studied extensively in the region of Mach reflection. Los Alamos Scientific Laboratory has published reports (12, 13) which include experimental and theoretical investigations of these phenomena. The mechanism of shock front propagation over a rectangular opening below a plane surface has been investigated by Ballistic Research Laboratories(14) and Princeton University(15). These investigations form the basis of much of the theory of this report.

Prior to UPSHOT-KNOTHOLE, there were no field test results published showing either peak pressures or pressure-time variation in field fortifications.

6.3 THEORY

The mechanism of reflection of a blast wave from a plane surface is described in The Effects of Atomic Weapons, where it is shown that the reflection coefficient (ratio of reflected to incident overpressure) of a blast wave on a rigid surface is a function of the incident overpressure and the angle of incidence. This is shown in Fig. 6.1, which was adopted from The Effects of Atomic Weapons. The incident overpressures used in the figure were chosen to be close to those which

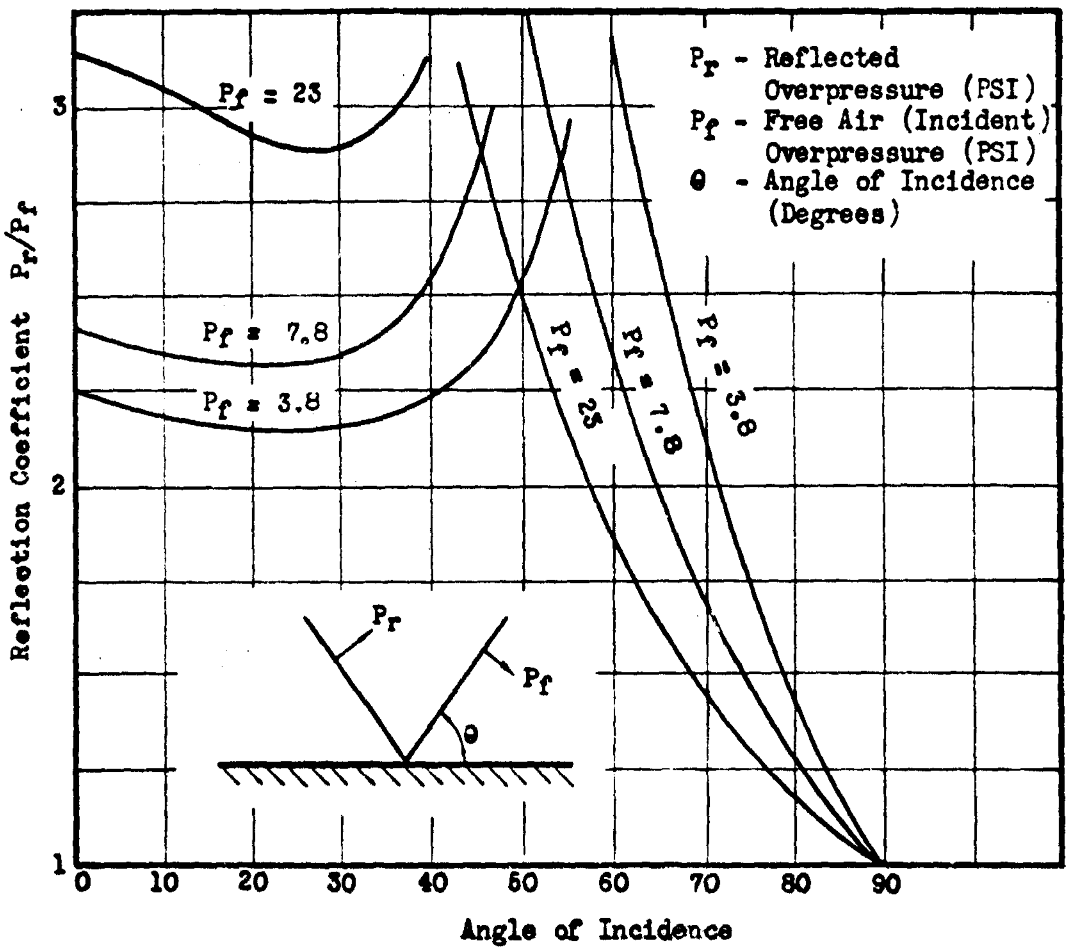


Fig. 6.1 Relation Between Incident Overpressure, Angle of Incidence, and Reflected Overpressure

were experienced during the test. Each curve shows a discontinuity at some point which seems to be a peak. The area to the right of this discontinuity is the region of Mach (irregular) reflection, while the left exhibits regular reflection. The curve is experimental; and, as more information becomes available, the discontinuities may be minimized. It serves to illustrate, however, that reflection coefficients of more than three can be expected under certain conditions.

Figure 6.2 is a cross section of a foxhole-type cavity showing the passage of a blast wave across a point "A" which is significant because it is in the same relative position as the Wiancko pressure-time gages used in this experiment. This and the following figures were based on shadowgraphs of shock tube studies made by BRL. Figure 6.3 shows the blast wave advanced slightly further and illustrates the passage of a second (reflected) blast wave, over the point "A." Figure 6.4 shows the blast wave in a further stage of advancement. Figures 6.5 and 6.6 illustrate how two more distinct reflected waves pass through the point "A." It follows that the time-overpressure relation in the cavity should have characteristics similar to Figure 6.7.

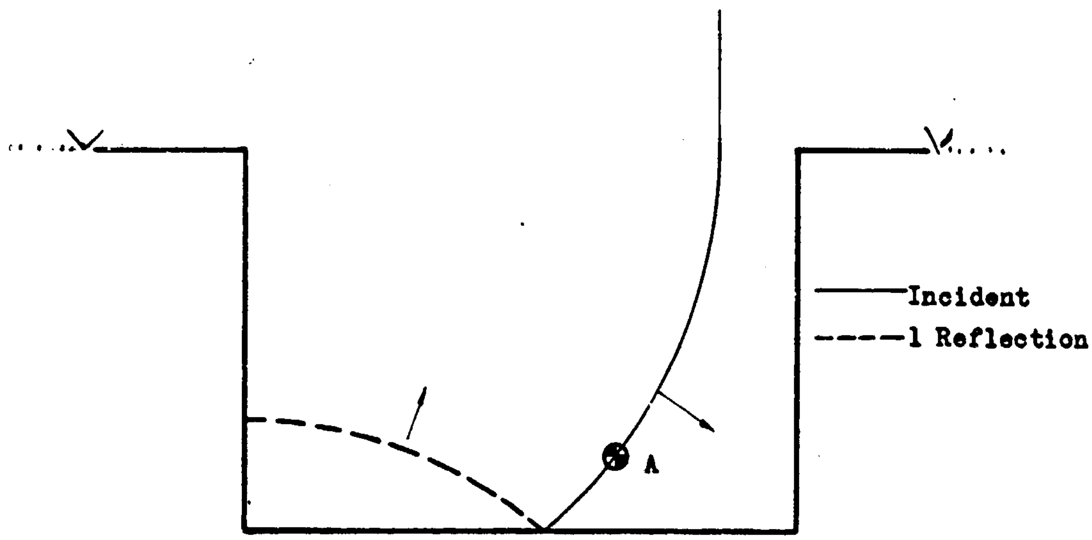


Fig. 6.2 Propagation of Pressure Waves in Foxhole - Time 1

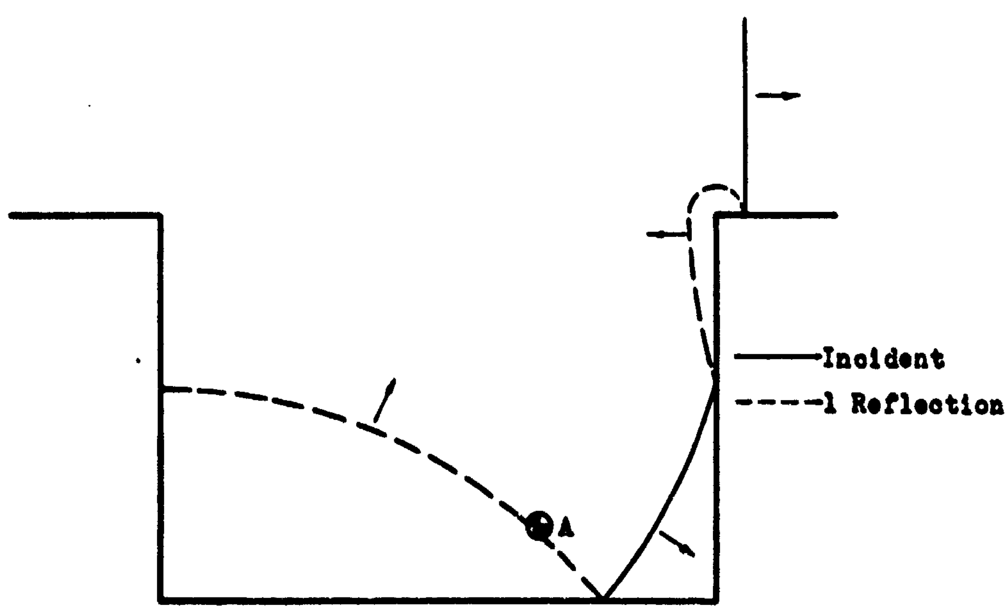


Fig. 6.3 Propagation of Pressure Waves in Foxhole - Time 2

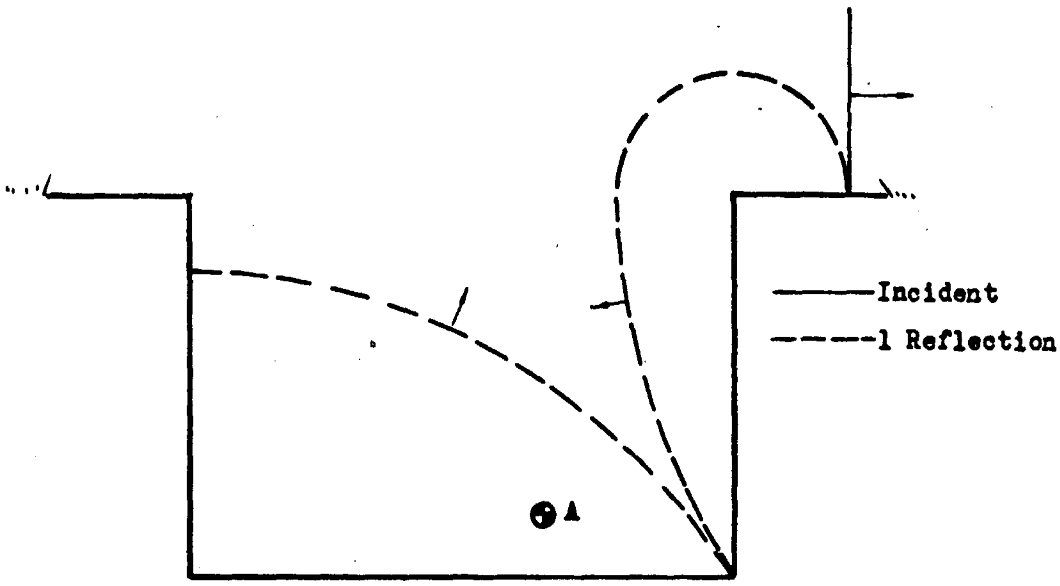


Fig. 6.4 Propagation of Pressure Waves in Foxhole - Time 3

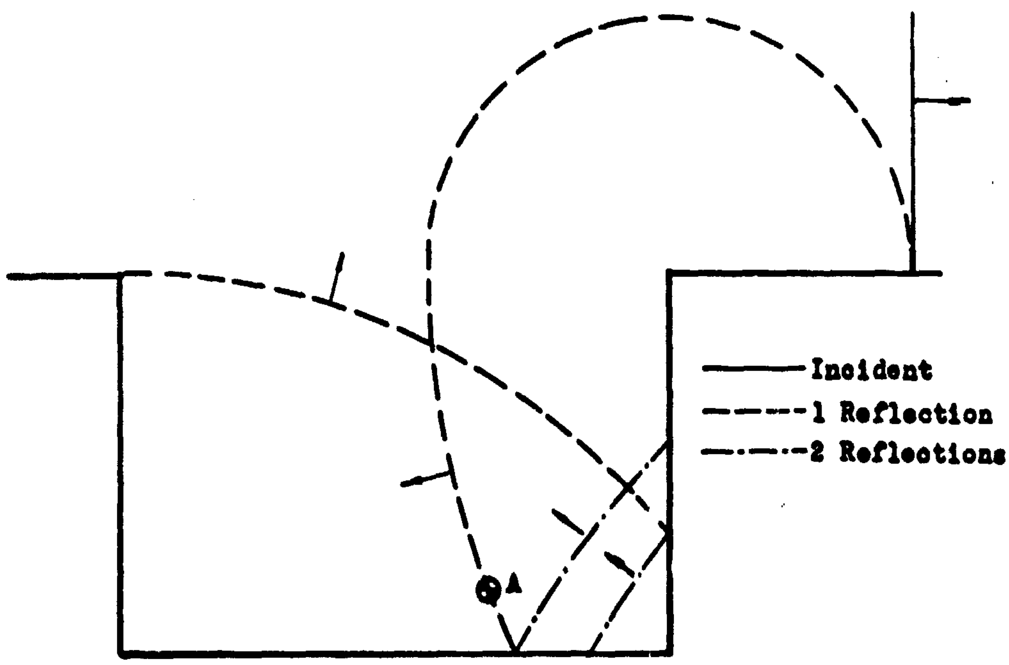


Fig. 6.5 Propagation of Pressure Waves in Foxhole - Time 4

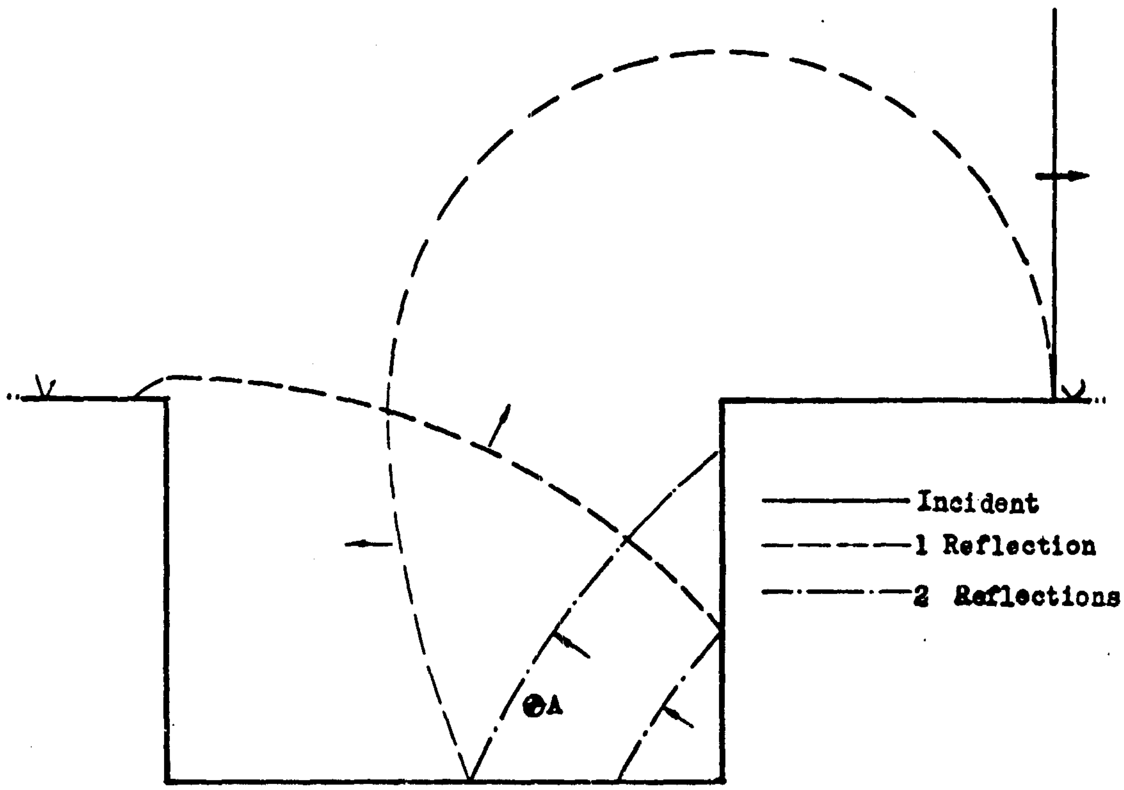


Fig. 6.6 Propagation of Pressure Waves in Foxhole - Time 5

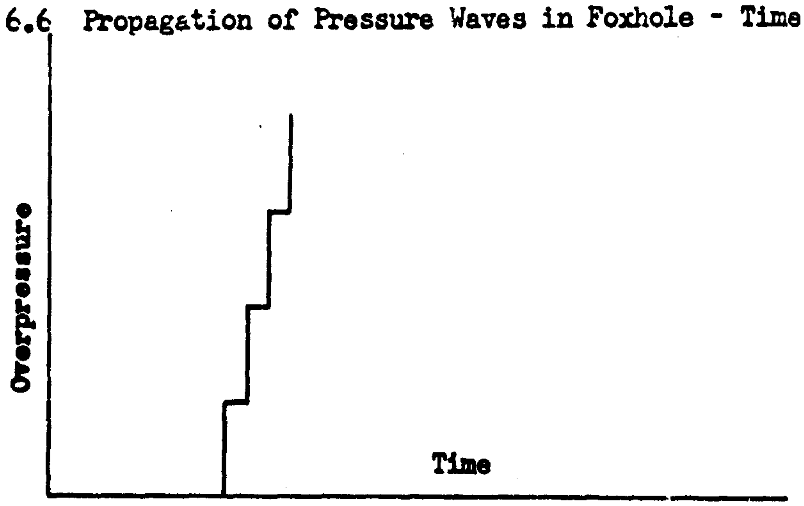


Fig. 6.7 Ideal Time-Overpressure Relationship in Cavity

The magnitude and time of the various steps in Fig. 6.7 depend upon such variables as the angle of incidence, incident overpressure, dimensions and aperture-volume relationship of the cavity, and position of point "A." The various surface irregularities, surfaces which are not perfect reflectors, and the interaction with the sidewalls will also tend to modify the shape of the curve. Because of the dependence of the wave propagation on the above-mentioned factors, the reflections shown in Figs. 6.2 to 6.6 give only an idealized representation of an actual situation.

CHAPTER 7

EXPERIMENT DESIGN

7.1 TEST STRUCTURES

The test facilities for Part II of Project 3.9 consisted of eight structures: four uncovered 2' x 4' x 6' foxholes; one 2' x 4' x 6' foxhole in which the aperture was two-thirds covered; and one each command post, machine gun emplacement, and covered foxhole. The latter three were concurrently used for the blast section of Project 3.9, and their physical appearance is fully described therein. They were emplacements 20, 25, and 30, respectively.

A diagram of the test site layout is given in Appendix A. The position of emplacements 20, 25, and 30 is given in Appendix B.

7.2 INSTRUMENTATION

Indenter peak pressure gages(10) developed and supplied by NOL, were used to obtain the peak overpressure in all of the emplacements.

Wiancko pressure-time gages (16,17) were used to obtain the time dependence of the overpressure as received in the foxholes. These were supplied and calibrated, and the traces were interpreted by NOL.

Pressure-time, scratch gages were used in the foxholes during Shot 10. They were supplied, calibrated, and their traces were interpreted by BRL.

Diagrams showing the placement of each gage are given in Figs. 8.1 to 8.8. The figures are placed, as a convenience to the reader, with their corresponding data sheets.

CHAPTER 8

RESULTS

8.1 INTRODUCTION .

The positions of the indenter, scratch, and Wiancko gages for each foxhole and emplacement are given in Figs. 8.1 to 8.8, which are development drawings of the emplacements. The small, numbered circles each represent an indenter gage position. The larger circles, with such notations as S-1 or W-1, represent scratch and Wiancko gages respectively. No dimensions are shown in the figures; however, they were drawn to scale to facilitate the exact location of the gage positions.

8.2 PRESENTATION OF DATA

Tables 8.1 to 8.8 are the results of all of the gage readings from each emplacement. The definitions of the headings of the tables are as follows:

Pgl - Ground level overpressure (psi).

d - Average of a series of readings of the diameter of the indentation in copper disk (millimeters).

k - Calibration factor - 82.6 psi/d^2.

Pmax - Maximum overpressure - kd^2 (psi).

Figures 8.9 to 8.24 are the pressure time curves obtained from the Wiancko and scratch gages. Their peak overpressures are given in Tables 8.1 to 8.5.

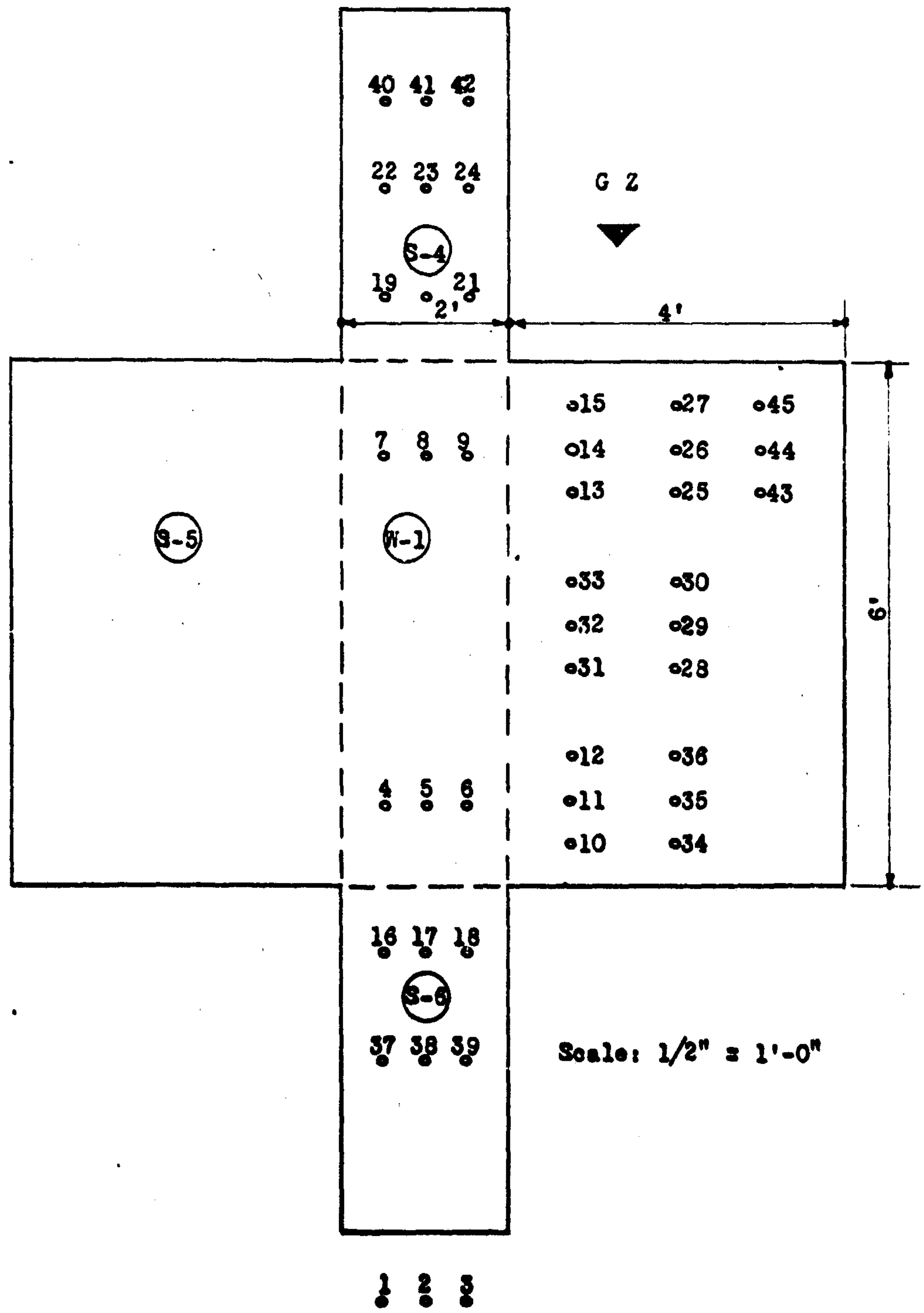


Fig. 8.1 Gage Positions - Foxhole 1

TABLE 8.1 - Overpressure Readings in Foxhole 1

Ground Level Overpressure: Shot 9 - 7.8 psi; Shot 10 - 4.6 psi

Gage Position	Shot 9				Shot 10			
	d	d_{ave}	P_{max}	P_{max}/P_{gl}	d	d_{ave}	P_{max}	P_{max}/P_{gl}
1	0.299				0.251			
2	0.287	0.307	7.8	*1.00	0.234	0.237	4.64	*1.01
3	0.335				0.225			
4	0.379				0.306			
5	0.386	0.389	12.5	1.60	0.474	0.305	7.68	1.67
6	0.401				0.303			
7	0.405				0.304			
8	0.389	0.397	13.0	1.67	0.299	0.300	7.44	1.62
9	0.398				0.297			
10	0.337				0.312			
11	0.432	0.385	12.2	1.56	0.308	0.310	7.94	1.72
12	0.387				0.309			
13	0.411				0.302			
14	0.621	0.493	20.1	2.57	0.439	0.347	10.0	2.17
15	0.448				0.299			
16	0.334				0.321			
17	0.378	0.379	11.9	1.53	0.304	0.296	7.25	1.58
18	0.376				0.263			
19	0.412				0.293			
20	0.418	0.414	14.1	1.81	0.312	0.300	7.44	1.62
21	0.412				0.296			
22					0.301			
23					0.304	0.305	7.85	1.71
24					0.311			

* Gage positions 1, 2, and 3 were at ground leve

TABLE 8.1 (Continued) - Overpressure Readings in Foxhole 1

Gage Position	Shot 9				Shot 10			
	d	dave	Pmax	Pmax/Pgl	d	dave	Pmax	Pmax/Pgl
25 26 27					0.302 0.307 0.286	0.298	7.34	1.60
28 29 30					0.303 0.381 0.362	0.349	10.1	2.20
31 32 33					0.295 0.299 0.278	0.291	7.00	1.52
34 35 36					0.356 0.238 0.284	0.293	7.09	1.54
37 38 39					0.275 0.321 0.291	0.296	7.25	1.58
40 41 42					0.273 0.265 0.313	0.284	6.67	1.45
43 44 45					0.293 0.292 0.302	0.293	7.09	1.54
W-1	-	-	14.6	1.87	-	-	N.G.	-
S-1 S-2 S-3					- - -	- - -	8.1 9.0 8.7	1.76 1.96 1.89

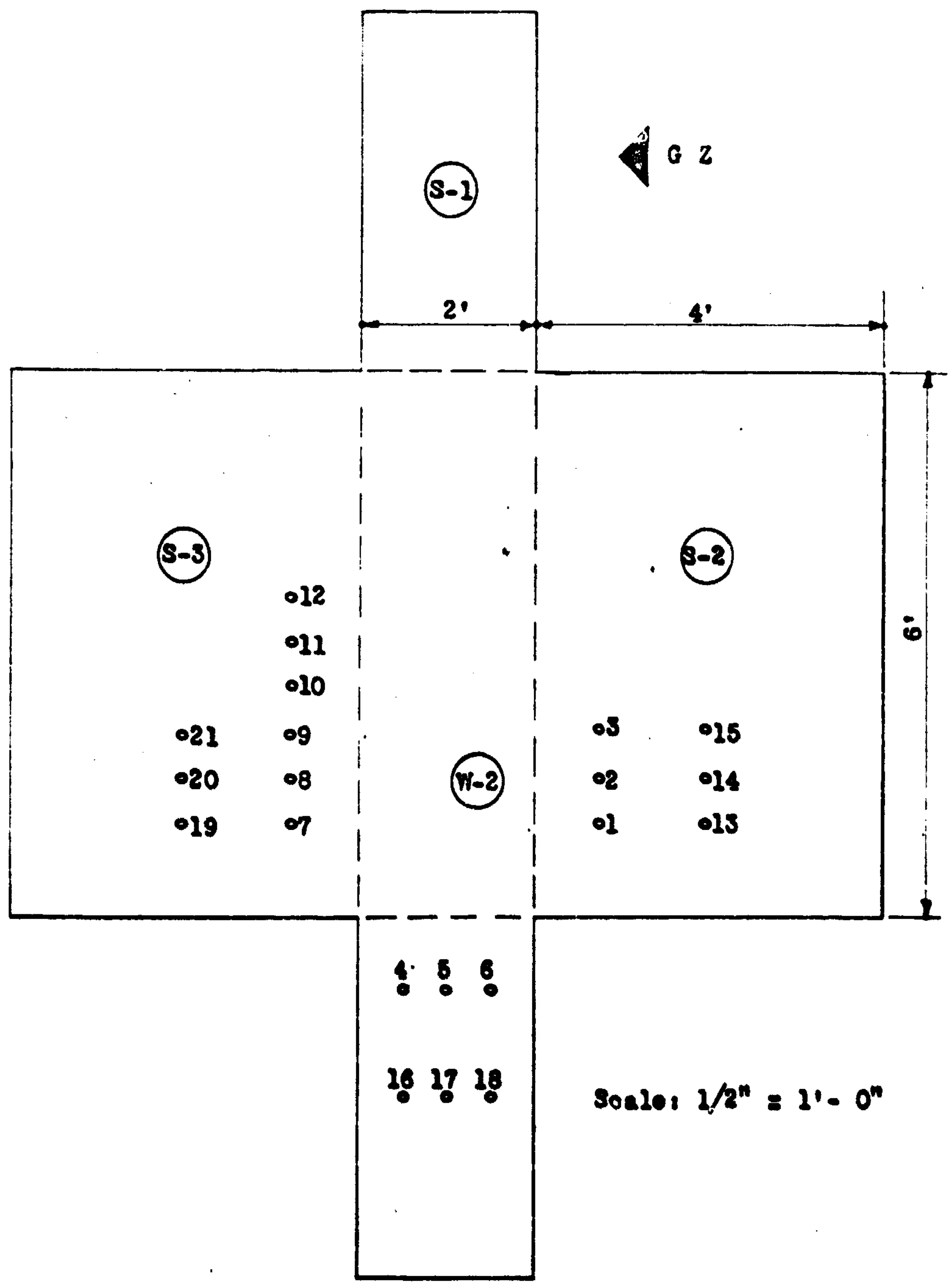


Fig. 8.2 Gage Positions - Foxhole 2

TABLE 8.2 - Overpressure Readings in Foxhole 2

Ground Level Overpressure: Shot 9 - 7.8 psi; Shot 10 - 4.6 psi

Gage Position	Shot 9				Shot 10			
	d	dave	Pmax	Pmax/Pgl	d	dave	Pmax	Pmax/Pgl
1	0.375				0.300			
2	0.397	0.380	11.9	1.53	0.293	0.294	7.14	1.55
3	0.367				0.288			
4	0.382				0.301			
5	0.433	0.401	13.3	1.70	0.243	0.261	5.64	1.22
6	0.389				0.240			
7					0.281			
8					0.301	0.290	6.95	1.51
9					0.284			
10	0.370							
11	0.378	0.374	11.5	1.47				
12	0.373							
13					0.276			
14					0.285	0.286	6.75	1.47
15					0.296			
16					0.285			
17					0.284	0.288	6.85	1.49
18					0.295			
19					-			
20					0.303	0.284	6.67	1.45
21					0.265			
W-2	-	-	13.9	1.78	-	-	7.9	1.72
S-1					-	-	8.8	1.91
S-2					-	-	9.1	1.98
S-3					-	-	8.5	1.85

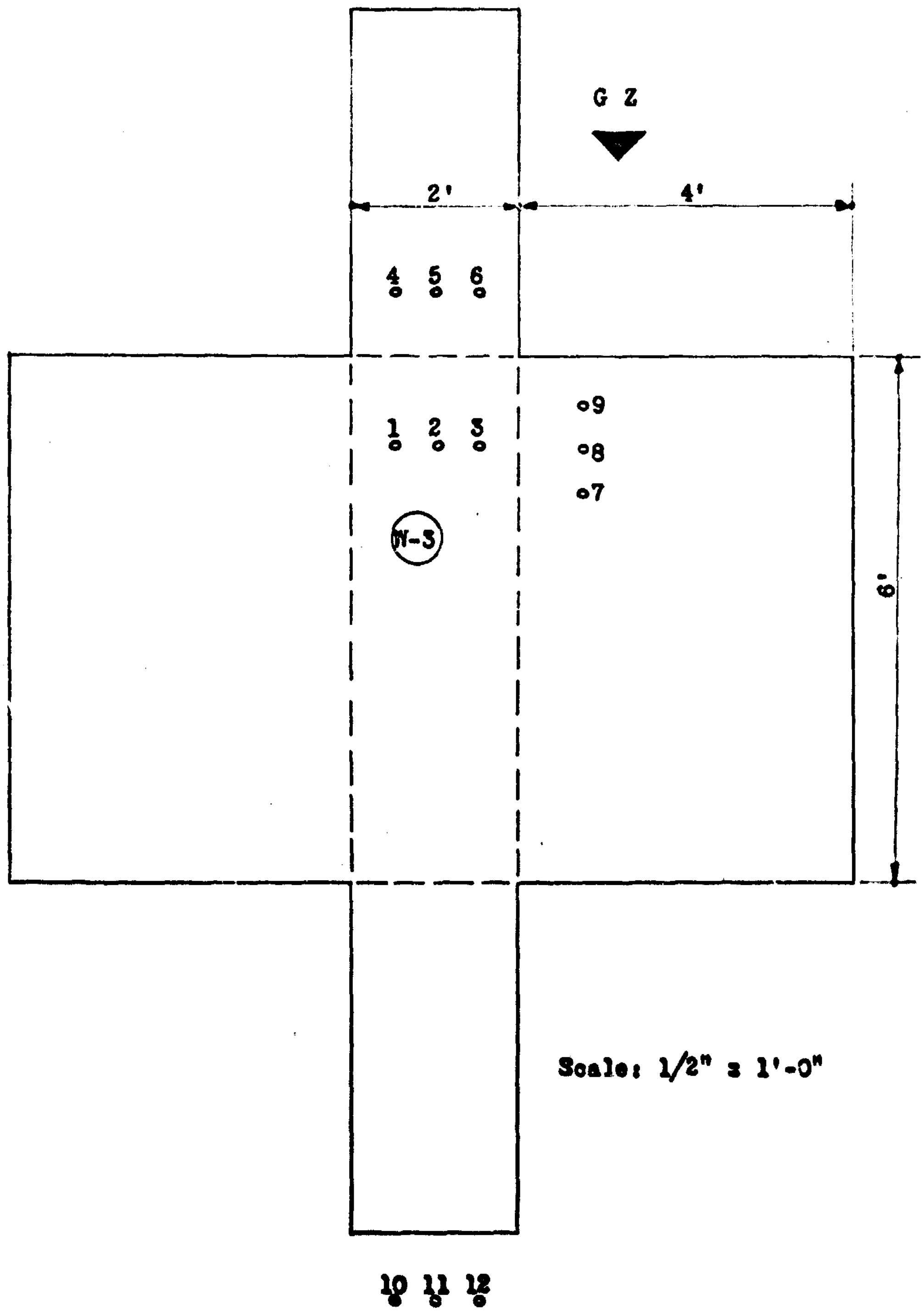


Fig. 8.3 Gage Positions - Foxhole 3

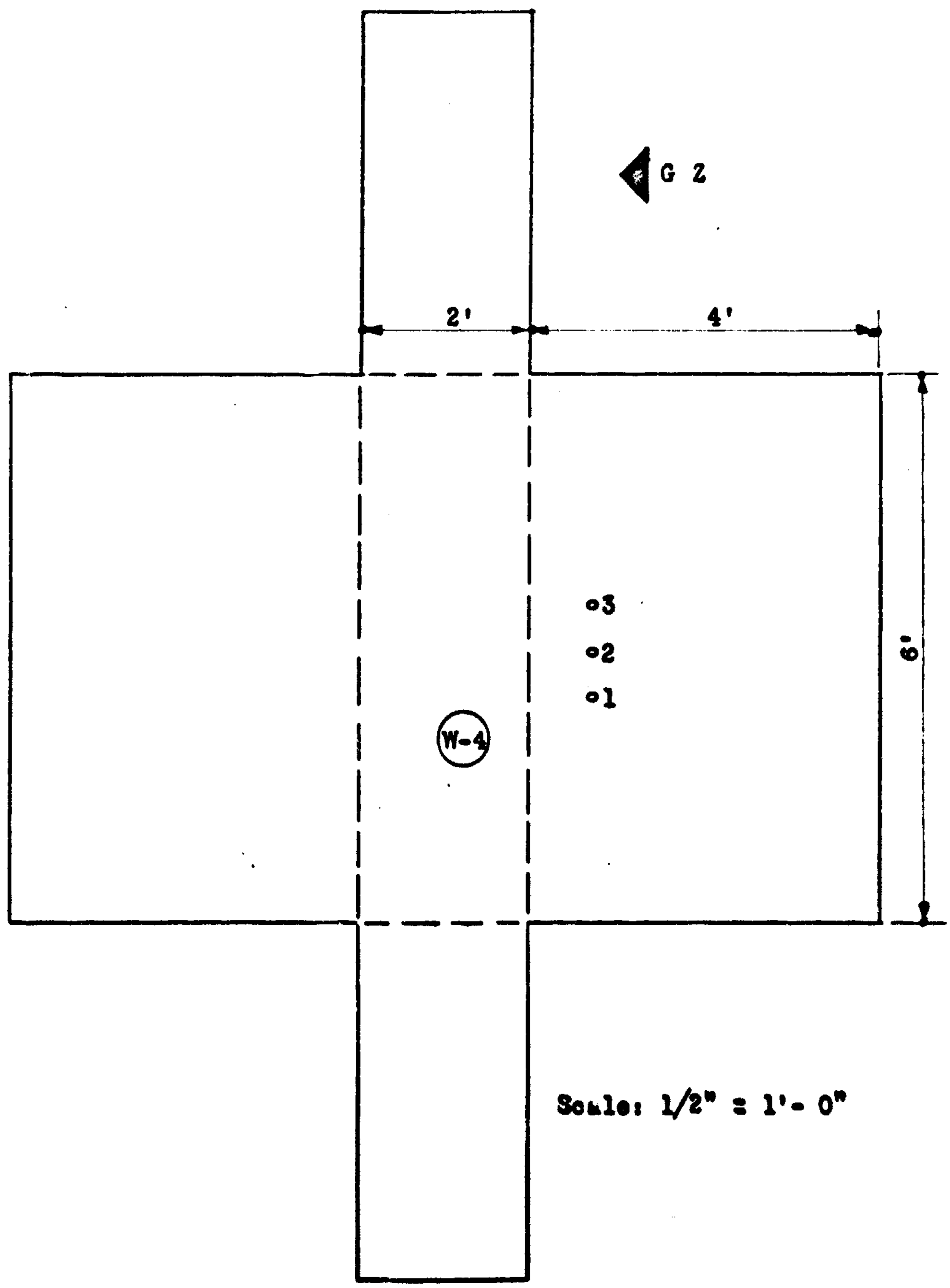


Fig. 8.4 Gage Positions - Foxhole 4

TABLE 8.3 - Overpressure Readings in Foxhole 3

Ground Level Overpressure: Shot 9 - 3.8 psi; Shot 10 - 1.8 psi

Gage Position	Shot 9				Shot 10			
	d	dave	Pmax	Pmax/Pgl	d	dave	Pmax	Pmax/Pgl
1 2 3	0.270 0.273 0.268	0.270	6.0	1.58				
4 5 6	0.259 0.275 0.275	0.270	6.0	1.58				
7 8 9	0.262 0.285 0.263	0.270	6.0	1.58				
10 11 12	0.219 0.215 0.220	0.218	3.92	*1.04				
W-3	-	-	6.2	1.63	-	-	3.0	1.67

* Gage positions 10, 11, and 12 were at ground level.

TABLE 8.4 - Overpressure Readings in Foxhole 4

Ground Level Overpressure: Shot 9 - 3.8 psi; Shot 10 - 1.8 psi

Gage Position	Shot 9				Shot 10			
	d	dave	Pmax	Pmax/Pgl	d	dave	Pmax	Pmax/Pgl
1 2 3	0.265 0.283 0.277	0.275	6.3	1.66				
W-4	-	-	6.3	1.66	-	-	2.8	1.55

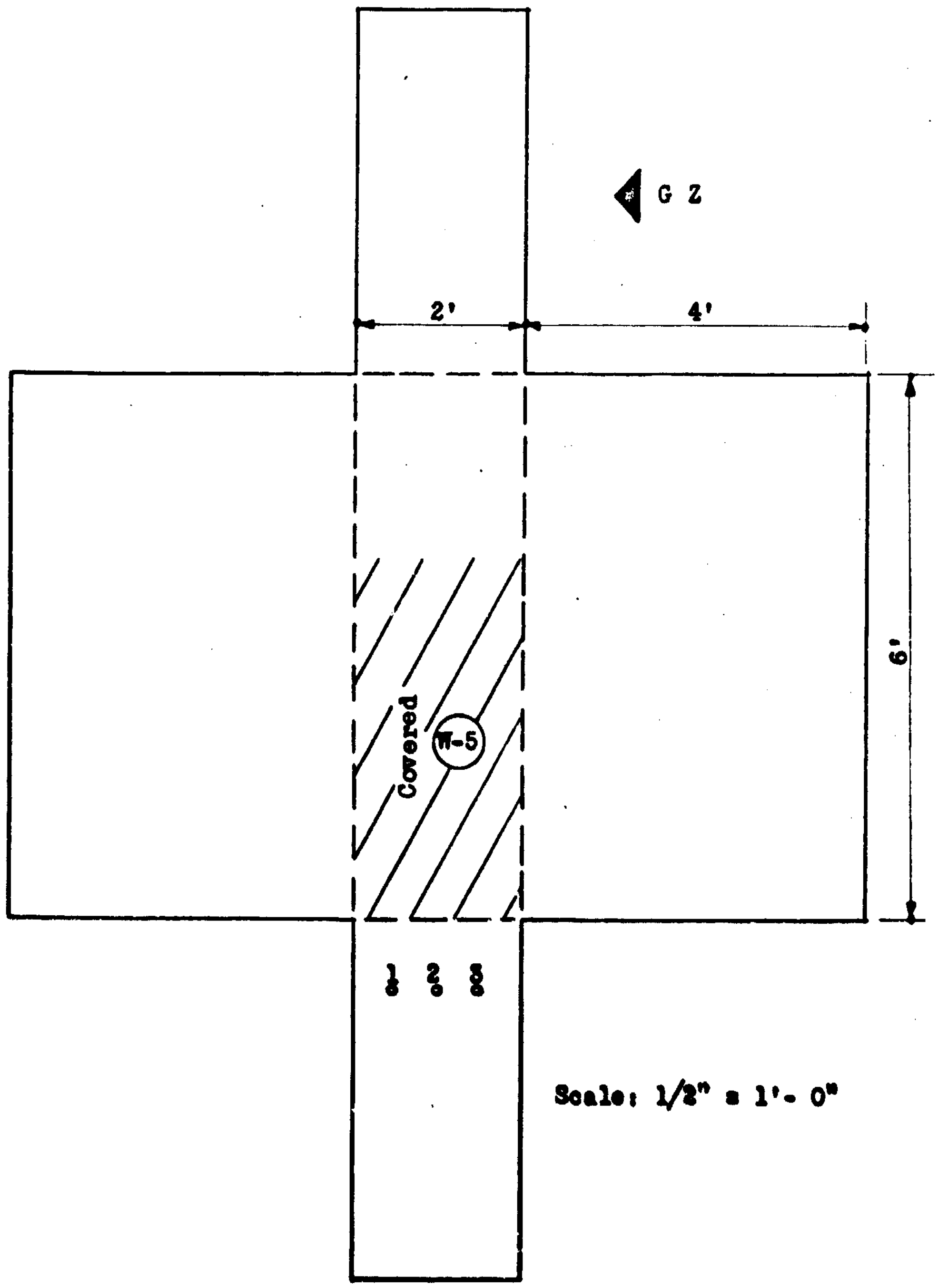


Fig. 8.5 Gage Positions - Foxhole 5 (2/3 Covered)

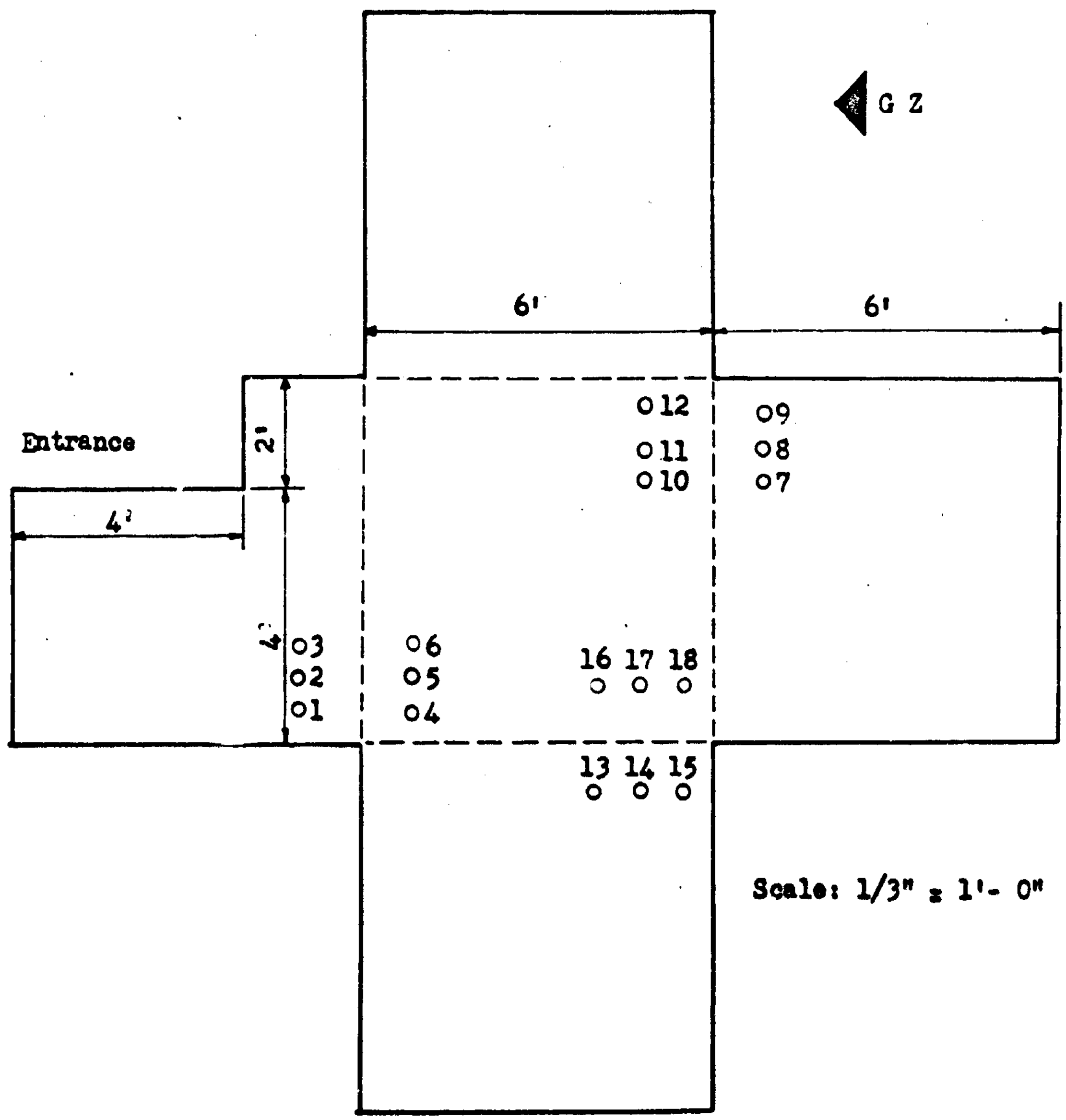


Fig. 8.6 Gage Positions - Command Post

TABLE 8.5 - Overpressure Readings in Foxhole 5 (2/3 Covered)

Ground Level Overpressure: Shot 9 - 3.8 psi; Shot 10 - 1.8 psi

Gage Position	Shot 9				Shot 10			
	d	dave	Pmax	Pmax/Pgl	d	dave	Pmax	Pmax/Pgl
1	0.249							
2	0.242	0.242	4.8	1.26				
3	0.235							
W-5	-	-	5.5	1.45	-	-	2.8	1.55

TABLE 8.6 - Overpressure Readings in Command Post

Ground Level Overpressure: 23 psi

Gage Position	Shot 9				Shot 10			
	d	dave	Pmax	Pmax/Pgl	d	dave	Pmax	Pmax/Pgl
1	0.457							
2	0.430	0.442	16.1	0.700				
3	0.440					Not Used		
4	0.427							
5	0.440	0.434	15.5	0.675				
6	0.434							
7	0.454							
8	0.462	0.449	16.7	0.725				
9	0.432							
10	0.438							
11	0.420	0.422	14.4	0.625				
12	0.408							
13	0.448							
14	0.430	0.435	15.6	0.678				
15	0.426							
16	0.453							
17	0.420	0.438	15.9	0.691				
18	0.441							

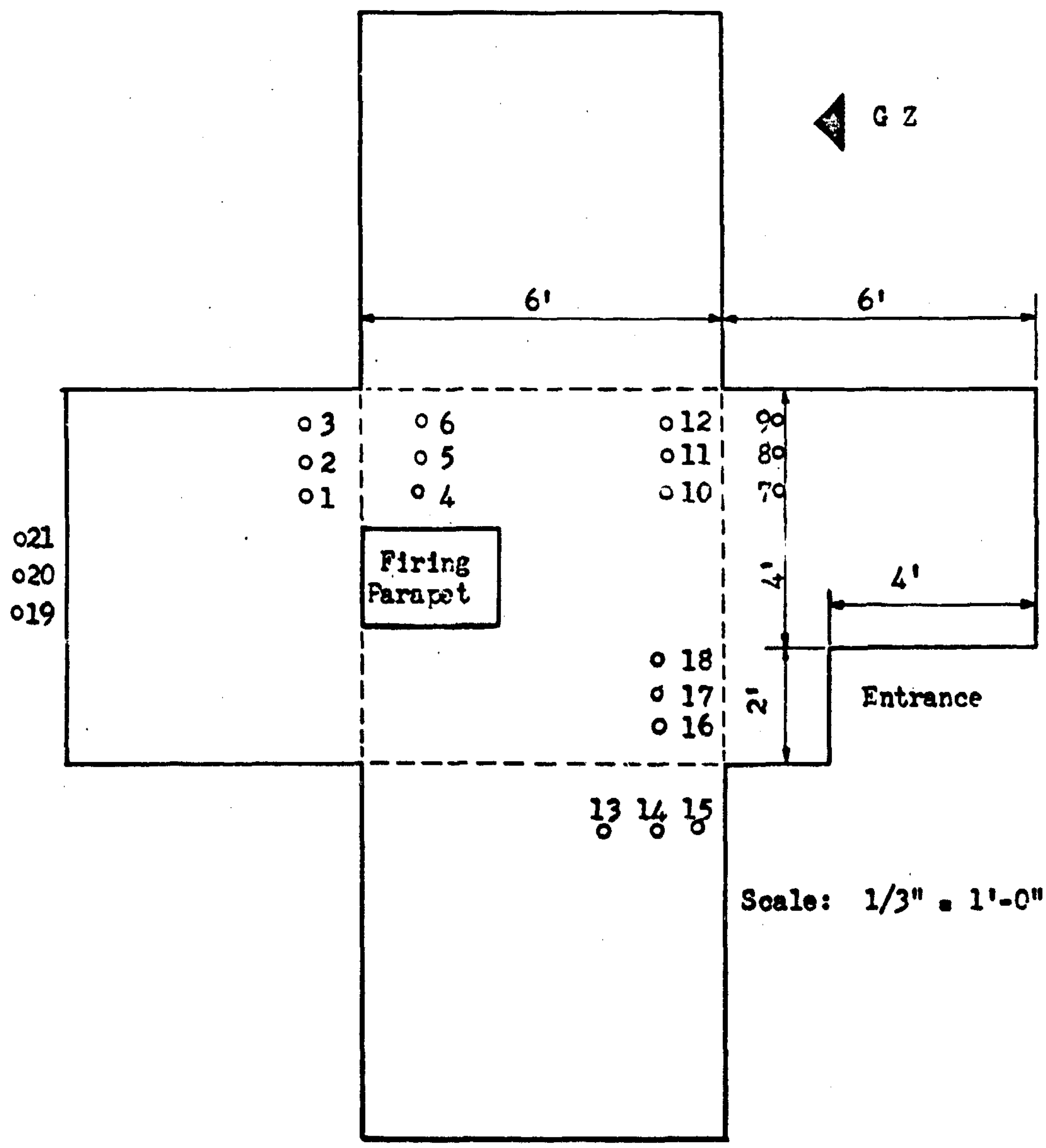


Fig. 8.7 Gage Positions - Machine Gun Emplacement

TABLE 8.7 - Overpressure Readings in Machine Gun Emplacement

Ground Level Overpressure: 23 psi

Gage Position	Shot 9				Shot 10			
	d	dave	Pmax	Pmax/Pgl	d	dave	Pmax	Pmax/Pgl
1 2 3	0.557 0.572 0.537	0.555	25.4	1.10		Not Used		
4 5 6	0.577 0.571 0.568	0.572	27.0	1.17				
7 8 9	0.619 0.605 0.692	0.639	33.7	1.47				
10 11 12	0.578 0.561 0.579	0.573	27.1	1.18				
13 14 15	0.535 0.536 0.563	0.545	24.5	1.07				
16 17 18	0.531 0.555 0.556	0.547	24.7	1.08				
19 20 21	0.529 0.518 0.541	0.529	23.0	*1.00				

* Gage positions 19, 20, and 21 were at ground level.

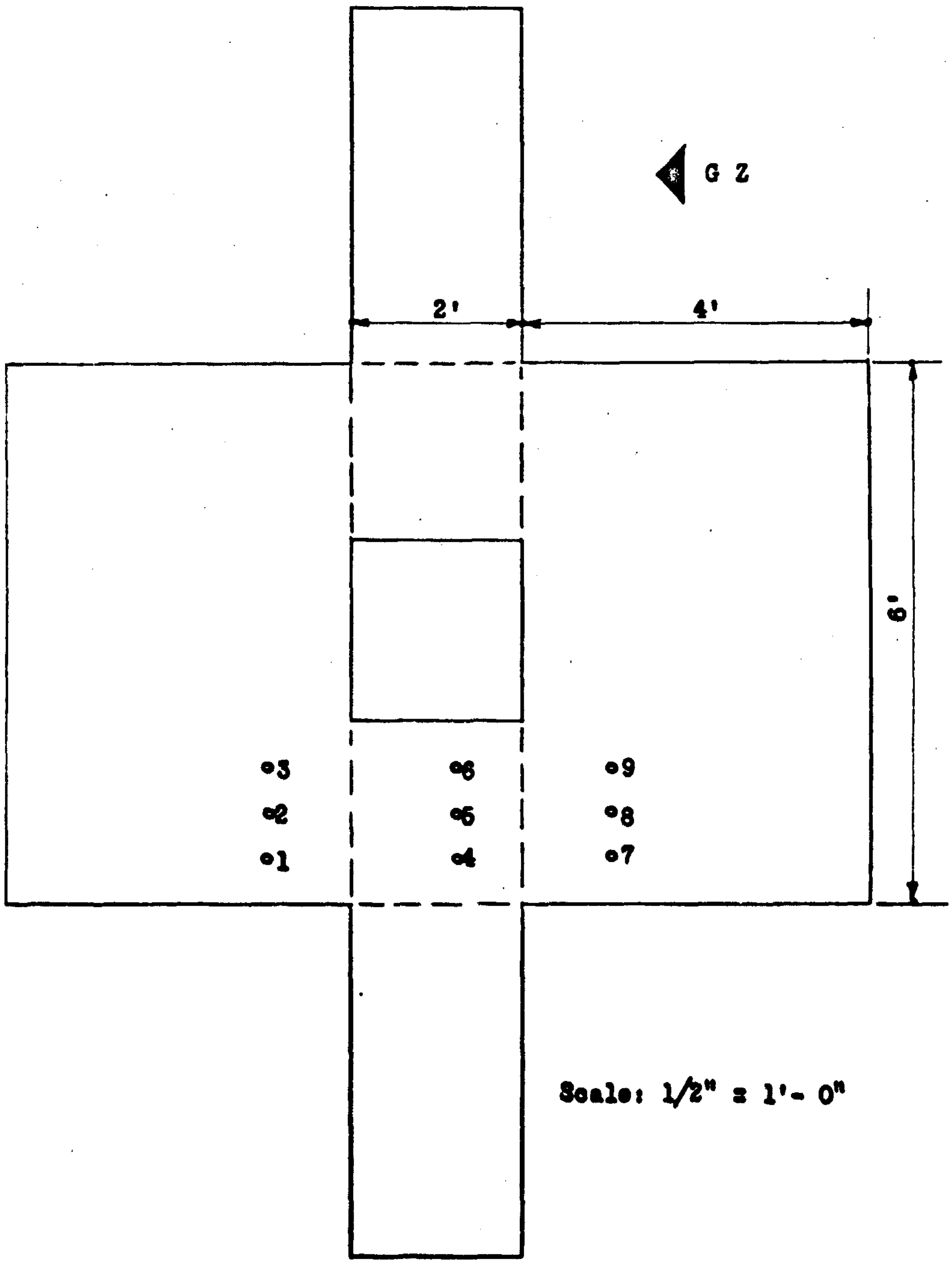


Fig. 8.8 Gage Positions - Foxhole (Covered)

TABLE 8.8 - Overpressure Readings in Covered Foxhole

Ground Level Overpressure: 23 psi

Gage Position	Shot 9				Shot 10			
	d	dave	Pmax	Pmax/Pgl	d	dave	Pmax	Pmax/Pgl
1	0.528							
2	0.531	0.528	23.0	1.00				
3	0.526					Not Used		
4	0.536							
5	0.545	0.537	23.8	1.04				
6	0.529							
7	0.528							
8	0.545	0.532	23.4	1.02				
9	0.523							

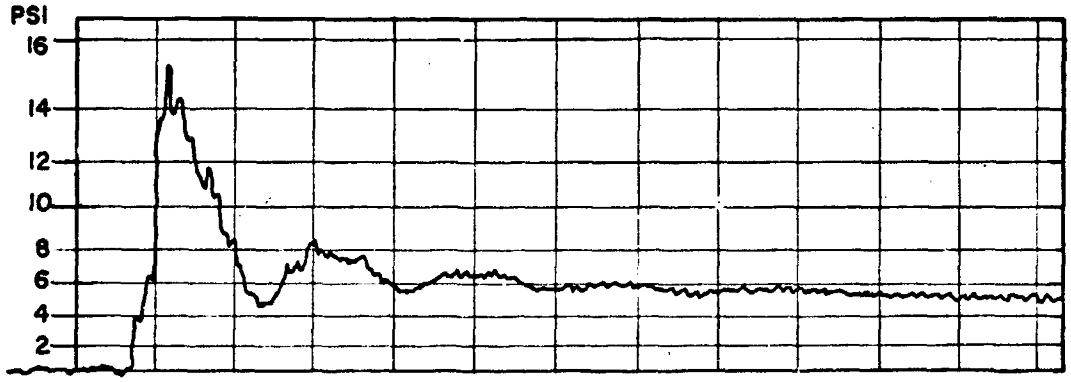


Fig. 8.9 NOL Wiancko Gage Record Shot 9, Foxhole 1

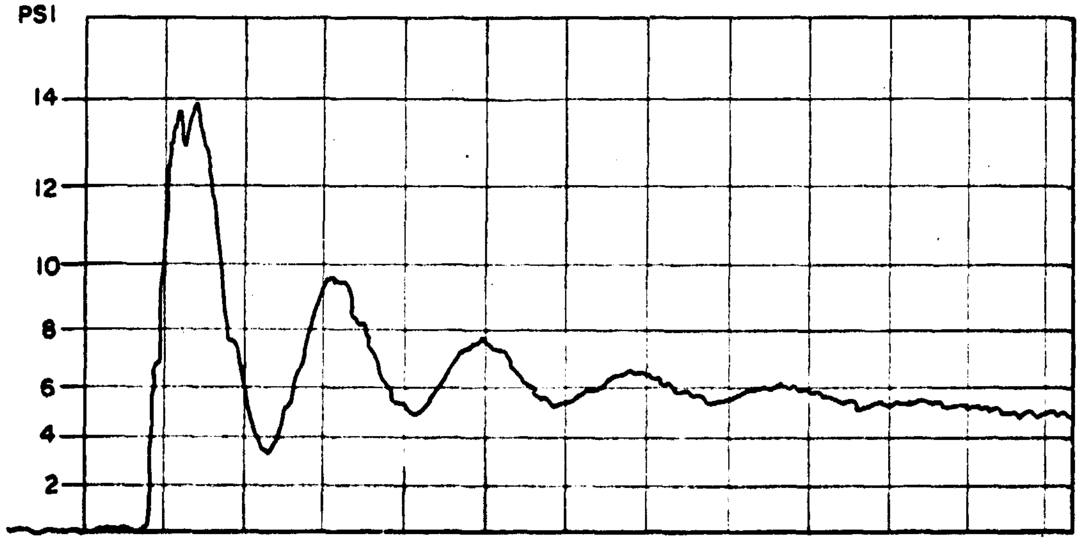


Fig. 8.10 NOL Wiancko Gage Record Shot 9, Foxhole 2

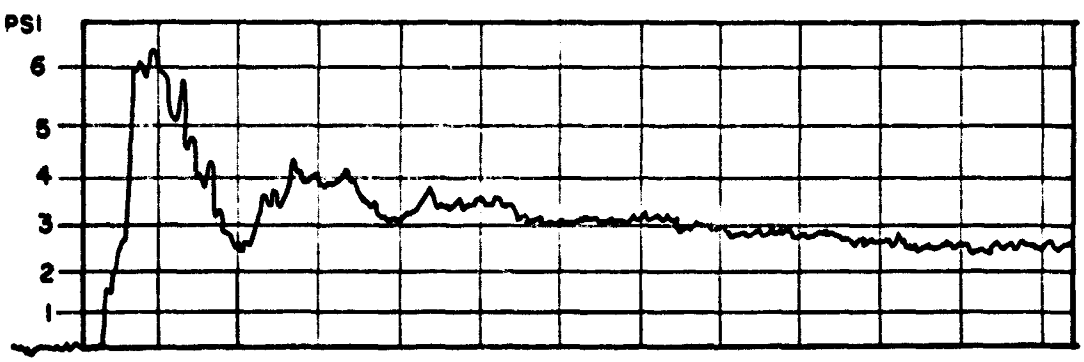


Fig. 8.11 NOL Wiancko Gage Record Shot 9, Foxhole 3

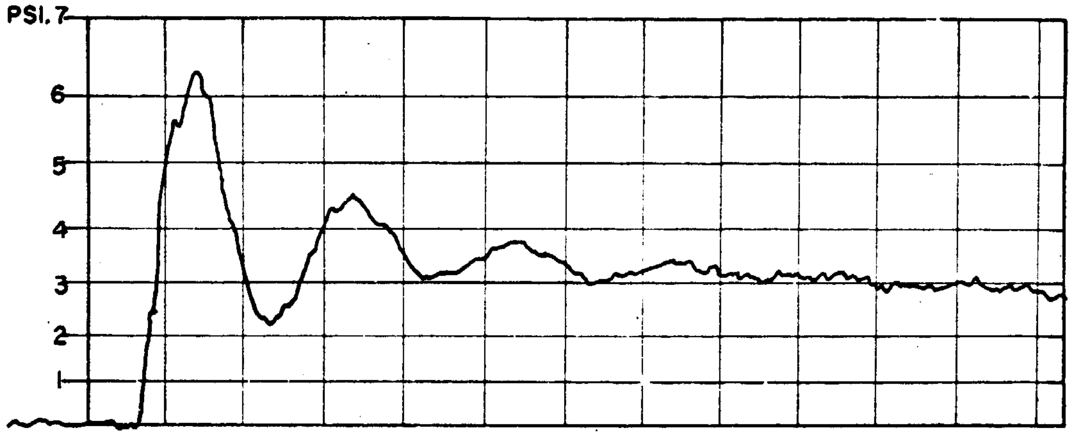


Fig. 8.12 NOL Wiancko Gage Record Shot 9, Foxhole 4

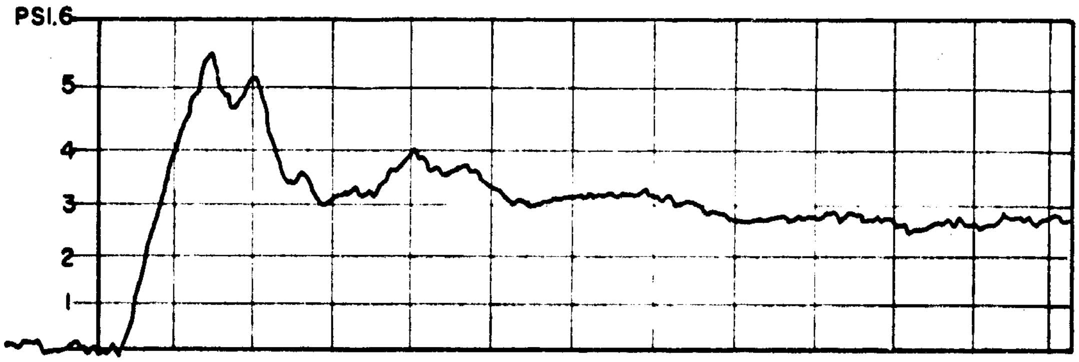


Fig. 8.13 NOL Wiancko Gage Record Shot 9, Foxhole 5

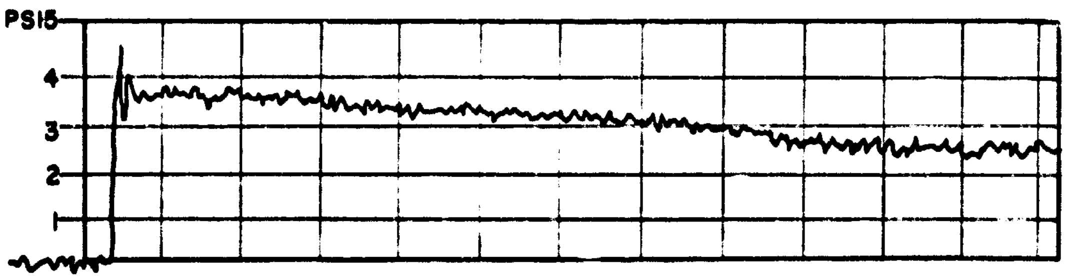


Fig. 8.14 NOL Wiancko Gage Record Shot 9, 7000 ft Ground Level

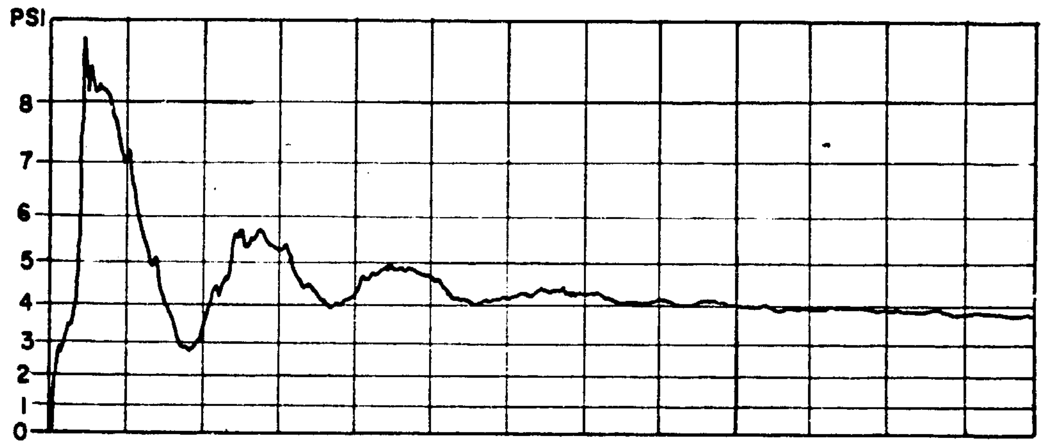


Fig. 8.15 NOL Wiancko Gage Record Shot 10, Foxhole 1

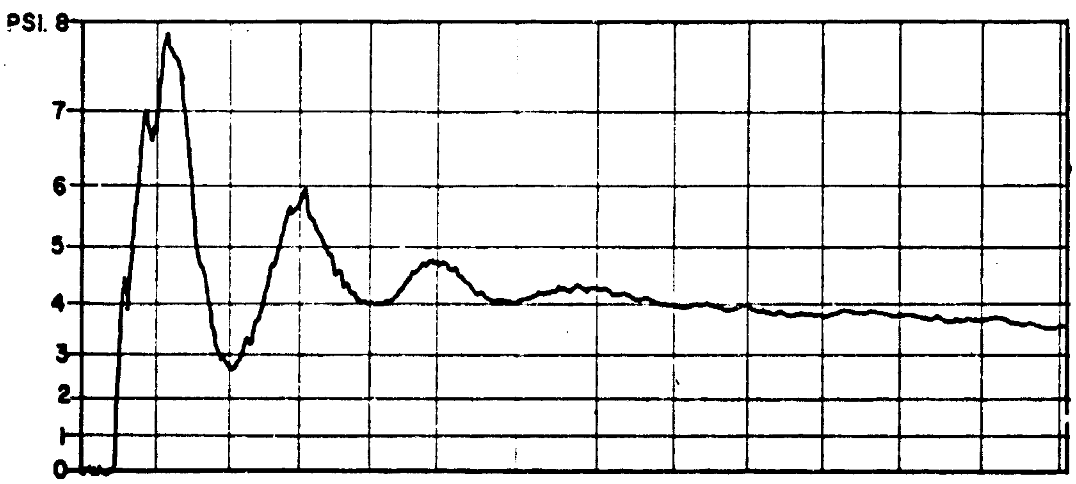


Fig. 8.16 NOL Wiancko Gage Record Shot 10, Foxhole 2

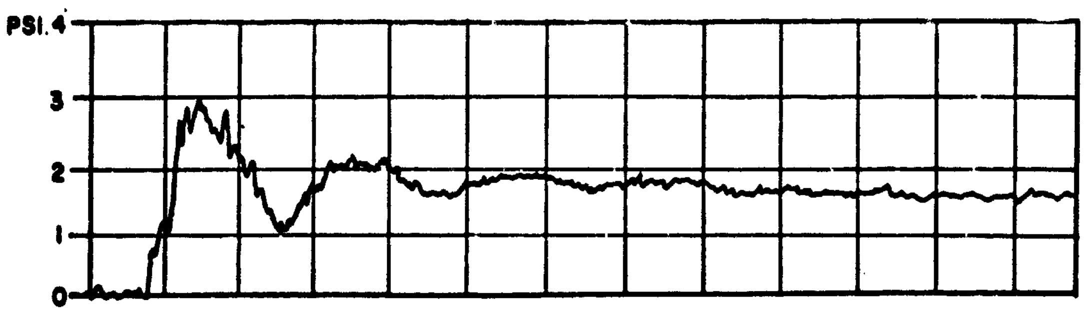


Fig. 8.17 NOL Wiancko Gage Record Shot 10, Foxhole 3

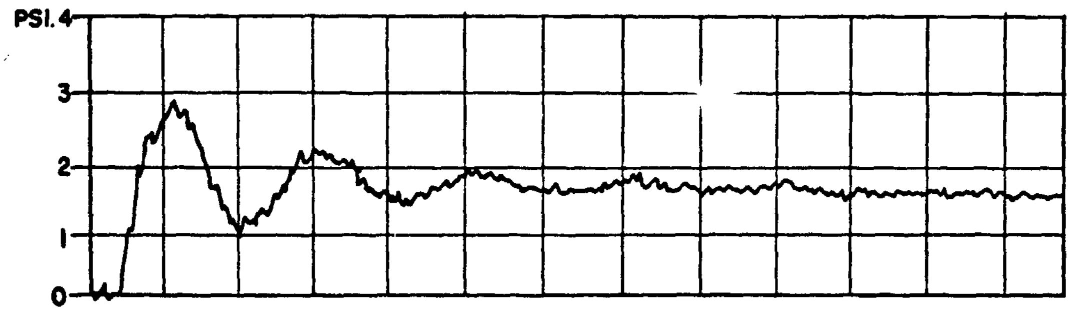


Fig. 8.18 NOL Wiancko Gage Record Shot 10, Foxhole 4

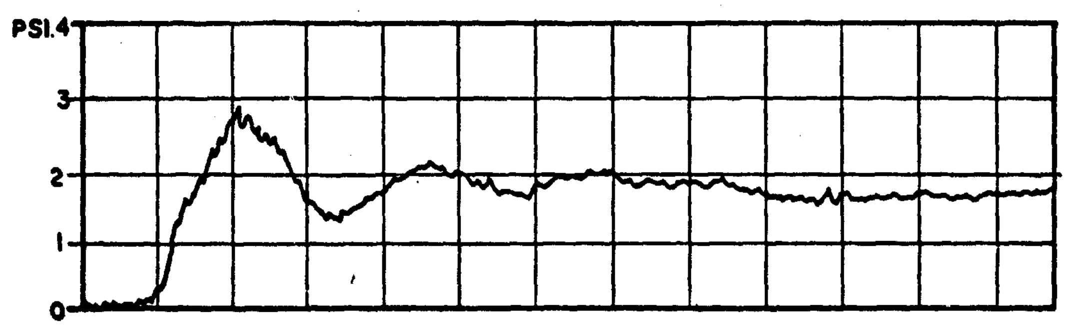


Fig. 8.19 NOL Wiancko Gage Record Shot 10, Foxhole 5

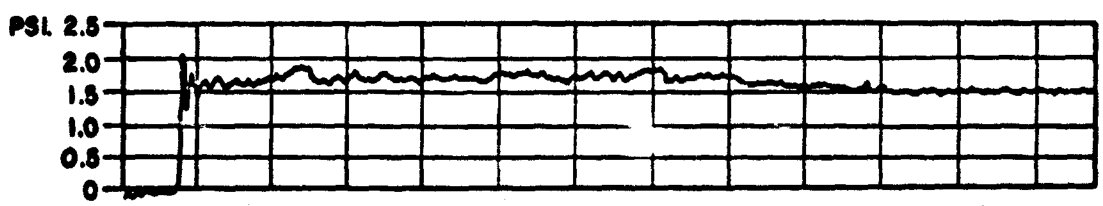


Fig. 8.20 NOL Wiancko Gage Record Shot 10, 7000-ft Ground Level

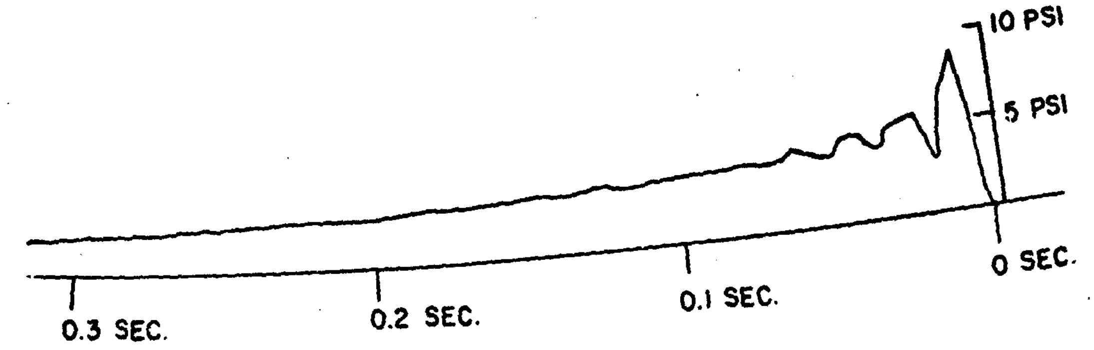


Fig. 8.21 BRL Scratch Gage Record Shot 10, Position S-4, Foxhole 1

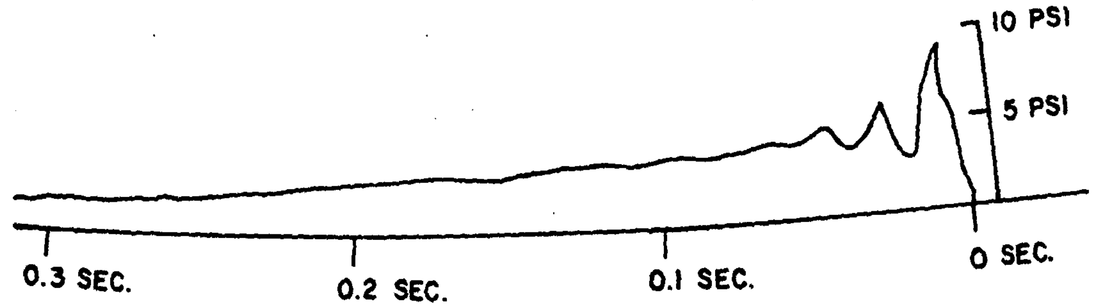


Fig. 8.22 BRL Scratch Gage Record Shot 10, Position S-6, Foxhole 1

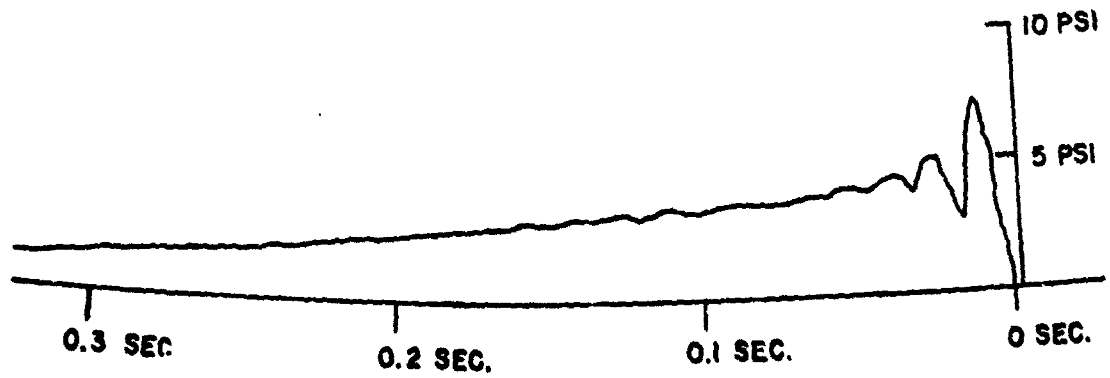


Fig. 8.23 BRL Scratch Gage Record Shot 10, Position S-2, Foxhole 2

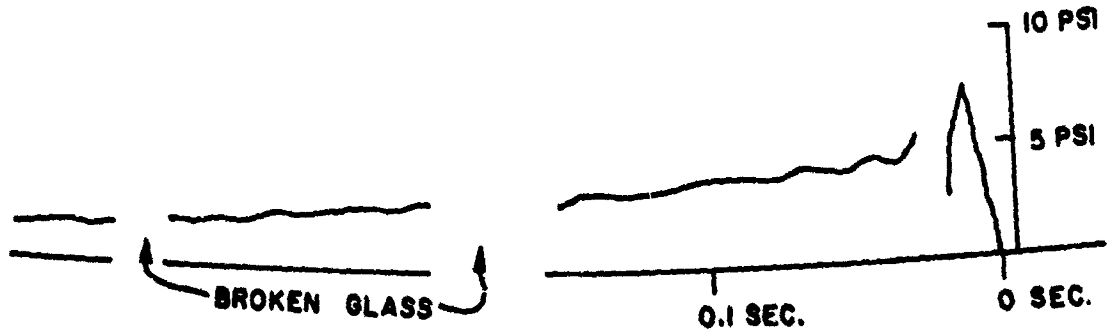


Fig. 8.24 BRL Scratch Gage Record Shot 10, Position S-3, Foxhole 2

CHAPTER 9

DISCUSSION

9.1 INTRODUCTION

To attain a complete understanding of the nature of overpressure multiplication (build-up) in a field fortification, it is necessary to determine such things as the effect of the size, geometry, and orientation of the emplacement; of the overpressure region in which the emplacement is exposed; of a partial cover; of an object, such as a soldier, in the emplacement; and of the material of the walls and floor. The design of this experiment included an insufficient amount of instrumentation to isolate these with certainty. Certain trends in multiplication and response of the instruments are indicated, and an introductory attempt is made to determine the significance of covers on the emplacement.

The function of a field fortification is to protect the individual soldier. Therefore, the results of this type of experiment should be integrated with the physiological effects of the overpressure on the individual soldier. Until this can be accomplished, the protective value of field fortifications from shock phenomena cannot completely be determined.

9.2 INSTRUMENTATION

9.2.1 Wiancko Gages

The traces of the Wiancko pressure-time gages given in Figs. 8.9 to 8.20 are of sufficient definition to enable a general verification of the predicted method of overpressure build-up in the emplacement.

Ideally, the overpressure build-up in an emplacement should follow the characteristics shown in Fig. 6.7, showing three and possibly more distinct "steps" in the process. Examination of the Wiancko gage traces reveals that the initial build-up is indeed characterized by a series of "steps." Each trace for both shots for foxholes 1 to 4 (those that were uncovered) shows at least two of these steps, the presence of which indicates that method of build-up described in the theory section of this report is valid, at least to the point where the third or possibly fourth pressure wave travels past the instrument.

The rise times from first initiation of the shock wave to the highest peak varied from 5 to 10 milliseconds (ms), differing considerably from the almost instantaneous build-up recorded at the surface. The duration of the first pulse was 10 to 20 ms, depending upon the emplacement. It is important to determine whether rise times and durations of this magnitude are physiologically dangerous.

The significance of the oscillatory nature of the traces after the initial peak is not known; however, certain general observations about them can be made. The period of the oscillations for each foxhole, whether oriented parallel or perpendicular to the blast, was between 16 and 22 ms, with most near 20 ms. The oscillations in the 2/3 covered emplacement were less evident than those recorded in the uncovered emplacement.

9.2.2 Scratch Gages

For Shot 10, foxholes 1 and 2 were further instrumented with scratch gages such that a pressure-time record on the walls of the emplacement could be obtained. The exact location of these gages is given in Figs. 8.1 and 8.2.

The traces of the scratch gages shown in Fig. 8.21 to 8.24 compare favorably with the Wiancko ~~gage traces, insofar as the peak pres-~~sure and times of the peaks are concerned. The sensitivity of these gages, however, was not sufficient to record the "steps" in the initial rise. Some slight variation in the time of the initial peaks was observed from gage to gage. It is felt that this was caused by the location of the gages in the emplacement. The gages S-1 and S-5 failed to operate except for recording the peak overpressure.

9.2.3 Indenter Gages

The indenter gages were used to augment the overpressure determinations made by the Wiancko and scratch gages, in order to determine whether any areas of unusually high overpressure existed at any point within the emplacements. For Shot 9, all of the emplacements were instrumented; while, for Shot 10, foxholes 1 and 2 were instrumented extensively with no indenter gages in the additional emplacements.

The peak overpressure values, as measured with the indenter gages, tended to remain relatively even throughout the emplacements. Where there was a considerable increase at some point, it is uncertain whether the extreme multiplication was caused by a high overpressure or some flaw in a gage; because the increase was often not demonstrated for both shots in the same emplacement or in emplacements in the same orientation. In all cases, the average of all the peak overpressures as measured by the indenter gages was within ± 15 per cent of that measured by the Wiancko gage. It is felt that indenter gages were sufficiently accurate and consistent for this experiment.

9.3 INTERPRETATION

Table 9.1 is a condensation of the data obtained from the Wiancko gages relating the overpressure multiplication, incident overpressure,

TABLE 9.1 - Summary of Data*

Emplacement	Overpressure Multiplication		Incident Over-pressure (psi)		Aperture (ft^2)	Volume (ft^3)	Aperture/Volume
	Shot 9	Shot 10	Shot 9	Shot 10			
Foxhole 1	1.87	-	7.8	4.6	12	48	0.25
Foxhole 2	1.78	1.72	7.8	4.6	12	48	0.25
Foxhole 3	1.63	1.67	3.8	1.8	12	48	0.25
Foxhole 4	1.66	1.55	3.8	1.8	12	48	0.25
Foxhole 5	1.45	1.55	3.8	1.8	4	48	0.083
Command Post	0.682	-	23	-	4	250	0.016
M. G. Emplacement	1.15	-	23	-	-	-	-
Foxhole (covered)	1.02	-	23	-	-	-	-

* Based on Wiancko gage results for foxholes 1 to 5 and indenter gage results for Command Post, M. G. Emplacement, and foxhole (covered).

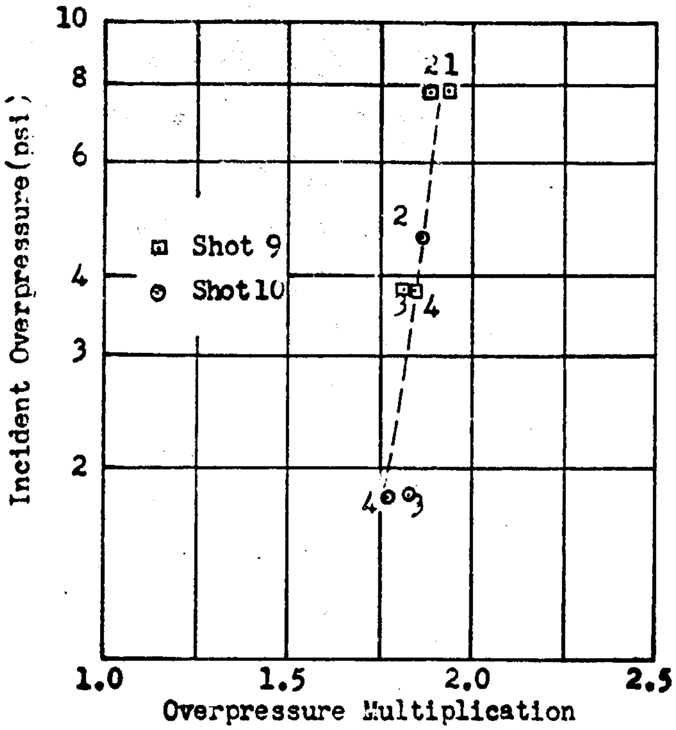


Fig. 9.1 Overpressure Multiplication Plotted as a Function of Incident Overpressure

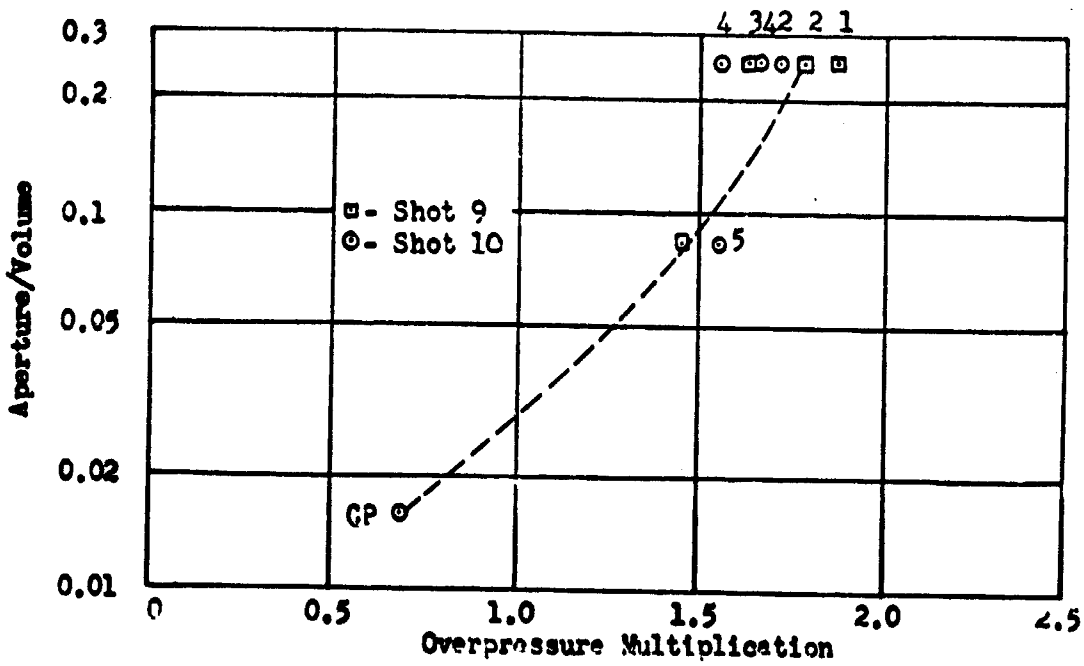


Fig. 9.2 Overpressure Multiplication Plotted as a Function of Aperture/Volume

aperture, volume, and the aperture-volume ratio for each emplacement. Data from the machine-gun emplacement and covered foxhole are not included in the subsequent discussion, because it was deemed that the type of cover used on these was not consistent with those used on the other emplacements. The remaining data give an indication of the importance of some of the parameters which affect the overpressure multiplication.

Plotting overpressure multiplication as a function of incident overpressure (Fig. 9.1) indicates--at least, in a preliminary nature--that the multiplication will increase with increased incident overpressure. Before a more reliable curve can be established, however, it is necessary to obtain a greater range of points on the graph.

Figure 9.2 shows the overpressure multiplication plotted as a function of aperture-to-volume ratio. The points are connected by a dotted line which serves only as an indication of the trend. A more definite relation could not be established; because, as is seen in Fig. 9.1, the overpressure multiplication is also a function of incident overpressure. Had there been more command posts and type 5 (2/3 covered) emplacements placed at various overpressure regions, it may have been possible to draw a series of curves similar to the dotted one shown in Fig. 9.2, each for a different incident overpressure.

The available data illustrate, however, that the overpressure multiplication within these emplacements is related to the aperture-to-volume ratio such that, as the aperture-to-volume ratio increases, the overpressure multiplication will also increase.

CHAPTER 10

CONCLUSIONS AND RECOMMENDATIONS

10.1 CONCLUSIONS

During this test, the overpressure multiplication as measured by the Wiancko gages in the open two-man foxholes was between 1.87 and 1.55; and the corresponding values for 2/3 covered two-man foxholes were between 1.45 and 1.55.

Instrumentation on the walls and floors of these foxholes indicates few overpressures unusually higher or lower than those indicated above.

A method of overpressure build-up in a foxhole has been predicted and verified with fair certainty.

The principal variables concerning overpressure multiplication in an emplacement are the incident overpressure and aperture-to-volume ratio.

10.2 RECOMMENDATIONS

Until the physiological significance to a human of overpressure with properties similar to those shown in the Wiancko gage traces is determined, it is recommended that no further full-scale field tests of these phenomena be attempted.

If further testing, whether laboratory or field, is warranted on the basis of the considerations delineated above, it is recommended that more data be obtained to fully determine the effects of incident overpressure and aperture-to-volume ratio on the overpressure multiplication, and that an attempt be made to determine whether orientation, materials of the walls and floor of the emplacement, and some object in the emplacement will markedly change the overpressure multiplication.

PART III

REFLECTED THERMAL RADIATION IN FOXHOLES

CHAPTER 11

INTRODUCTION

11.1 OBJECTIVES

The objectives of Part III of Project 3.9 were to measure the thermal radiation from an atomic bomb in the shadowed portion of a standard, 2' x 4' x 6', two-man foxhole; and to determine a method of scaling such that the reflected thermal energy in a foxhole may be predicted for any atomic weapon yield, height of burst, distance from ground zero, and reflectance of exposed wall.

11.2 BACKGROUND

During the DESERT ROCK operations(18), much work but little correlation was done to illustrate the gross effects of a nuclear detonation on field fortifications. These emplacements, in general, were constructed to illustrate effects graphically to the troops participating in the operation, with little or no attempt at instrumentation or recording of results. The blast and overpressure sections of this report have attempted to obtain more definite information on blast effects.

Measurements have been made of the gamma radiation intensity and the neutron flux in a standard two-man foxhole(6,19).

The protective value of standard field emplacements from thermal radiation has been illustrated qualitatively in the DESERT ROCK operations, and it has been generally agreed that adequate protection is afforded except in extreme conditions where a large portion of the emplacement is directly exposed. In a quantitative sense NML instrumented one foxhole with passive thermal indicators for one shot of the BUSTER series. Eighteen cal/cm^2 were received on the directly exposed wall, but little measurable reflected energy was received on the unexposed walls or floor(20).

Little more than this was known about the reflected thermal energy within an emplacement, which indicated a need to determine this quantity, and to develop means of scaling this information to many conceivable operational conditions.

11.3 THEORY

The successful completion of an experiment of this type depends upon achieving a balance between the actual conditions experienced by the soldier in combat and modifications which are necessary to provide convenient, reliable experimental measurements. During the conduct of the field test, these modifications should be kept at a minimum, providing accurate operations are not impaired.

To accomplish the objectives, a series of foxholes representative of the basic type of emplacement most used in combat were instrumented. They were lined with aluminum which was treated with an "Alzak" process, giving the surface high diffuse reflectance characteristics(21). (Averages 70.7 per cent over the 400 to 1100 micron wavelength range.) This material was chosen because polar reflectance curves of sand and soil indicate that they are essentially diffuse reflectors, and the walls of the foxhole should have similar reflectance characteristics(22). Aluminum was used because it was desirable to have a reflector whose characteristics would remain unchanged through the entire thermal pulse. This generally would not be the case for paints or most otherwise suitable diffusely reflecting surfaces.

Briefly, a diffuse reflector is one in which the energy intensity measured at any angle from the normal to the reflecting surface is proportional to the cosine of this angle multiplied by the intensity of the reflected energy in the normal direction. In mathematical form:

$$I_\theta = I_n \cos \theta$$

where I_θ = energy intensity at angle θ from the normal to the surface

and I_n = energy intensity in normal direction to the surface.

CHAPTER 12

EXPERIMENT DESIGN

12.1 GENERAL

A series of 22 two-man foxholes instrumented to measure thermal energy were exposed to Shots 9 and 10. Each was lined with aluminum sheet, the surface of which was treated to be a diffuse reflector, and was oriented for each shot such that the direct thermal energy was incident either 1 ft, 2 ft, 3 ft, or 4 ft down the directly exposed wall, or 2 ft across the floor. This was accomplished by placing all foxholes (except those used for calorimeters and scaling) in the same immediate area and orienting each one in the ground at an angle such that the desired amount of back wall was directly exposed as shown in Figs. 12.1 and 12.2. The area around the foxholes was subsequently stabilized to minimize preshock dust, an effect which will vary considerably with soil conditions.

12.2 TEST SITE LAYOUT

Eighteen foxholes were placed 4000 ft from estimated ground zero on the East-West blast line, two were placed at 6000 ft, and one at 8000 ft from planned ground zero on the Forest Service Line.

A diagram of all Project 3.9 emplacements is given in Appendix A.

12.3 INSTRUMENTATION

Each foxhole was instrumented with an array of passive indicators placed to provide measurements of the thermal energy distribution for each orientation (area of back wall exposed). For those emplacements in which the long (6 ft) edge was perpendicular to a radial line from the bomb, measurements were taken along a vertical line 1 ft from the directly exposed wall. When the long (6 ft) side was parallel to a radial line from the bomb, measurements were made along vertical lines 1½ ft, 3 ft, 4 ft, and 4½ ft from the directly exposed wall and along horizontal lines 1 ft, 2 ft, and 3 ft from the top of the foxhole. To eliminate shielding of the passive indicators by the supporting frame, a series of foxholes were often necessary for each orientation. The purpose of each is given in Appendix E, and was the same for each shot.

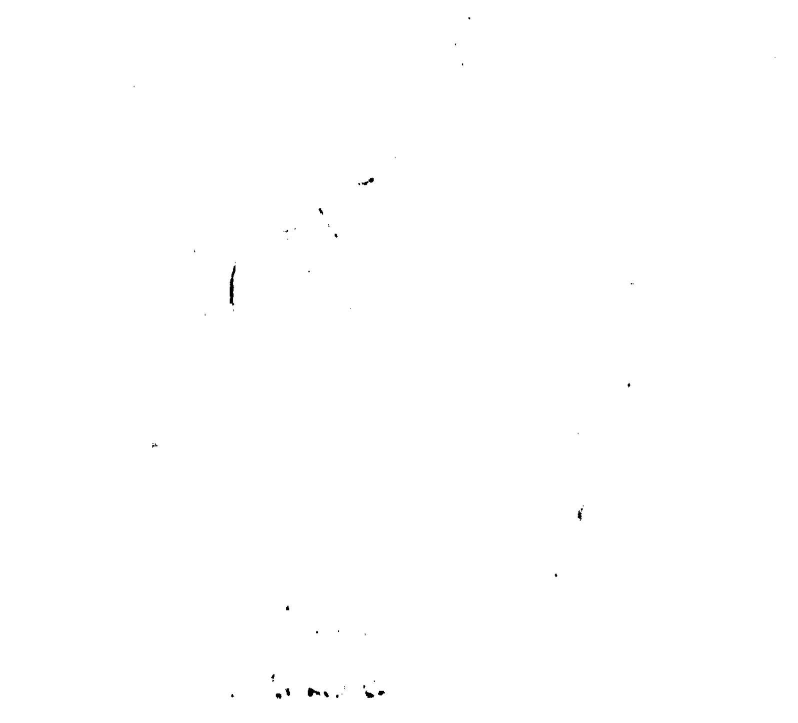


Fig. 12.1 Foxhole 63 A

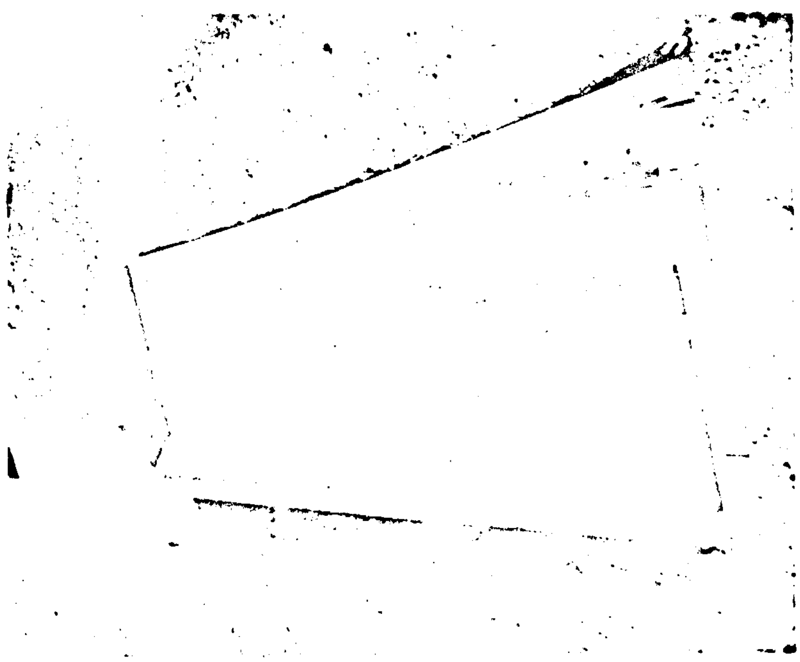


Fig. 12.2 Foxhole 70 A

Furthermore, at the 6000 ft and 8000 ft stations, calorimeters were utilized to measure the reflected thermal energy. They were placed parallel to the passive indicators in order to obtain a direct comparison with the total energy as measured by the passive indicators.

12.4 THERMAL INDICATORS

The passive indicators consisted of carbon paper, M-6 liquid vesicant detector paper, black matt paper, cherry bond paper, and buff bond paper which were developed and supplied by NML. These react to various thermal energies from 0.45 cal/cm^2 for the M-6 liquid vesicant detector paper to 14 cal/cm^2 for the buff bond paper. They were cut into ½ in. wide x 12 in. long strips and mounted with cellophane tape on ¼ in. x 3 5/8 in. x 12 in. plywood panels. With the necessary space between passive indicator strips for firebreaks, it was possible to mount four strips per plywood panel. The panel assembly was then painted with an acryloid gloss type fire-resistant paint exposing eight evenly spaced ¼ in x 3/4 in. "windows" per indicator strip. For certain applications, panels 9 1/8 in. long and 2 in. long were assembled.

The calorimeters were supplied by the Naval Radiological Defense Laboratory. They consisted essentially of a suitably mounted disk-shaped blackened copper energy receiver with a thermocouple soldered to its unexposed face(23). With appropriate recording devices, it was possible to obtain the time-temperature characteristics of the copper disk during exposure. This could then be converted to a curve giving the total energy received as a function of time.

CHAPTER 13

RESULTS

13.1 DATA ANALYSIS

The reflected thermal energy as measured in the foxholes was made independent of the direct thermal energy by representing, wherever there was a passive indicator reaction, the reaction energy as a fraction of the direct thermal energy. Thus, if the indicator reaction energy was 5.6 cal/cm^2, and the direct energy was 40 cal/cm^2, the fraction is then 5.6 cal/cm^2/40 cal/cm^2 = 0.140. In this manner, the data obtained from corresponding foxholes for Shots 9 and 10 were combined into a single set of data.

It was necessary to compensate for variations in wall area caused by slight errors in orientation of emplacements and the difference between actual and planned ground zero. Accordingly, if the exposed area was planned to be 2 ft^2, but was actually 1.5 ft^2, the fraction at each indicator reaction point was multiplied by 2 ft^2/1.5 ft^2 = 1.33 to give the fraction had 2 ft^2 been exposed. In addition, this figure was then multiplied by a constant factor (1/Reflectance of aluminum = 1/0.707 = 1.42) to give the fraction of incident energy had the reflectance of the walls been unity. Appendix F gives the complete thermal data.

13.2 PASSIVE INDICATORS

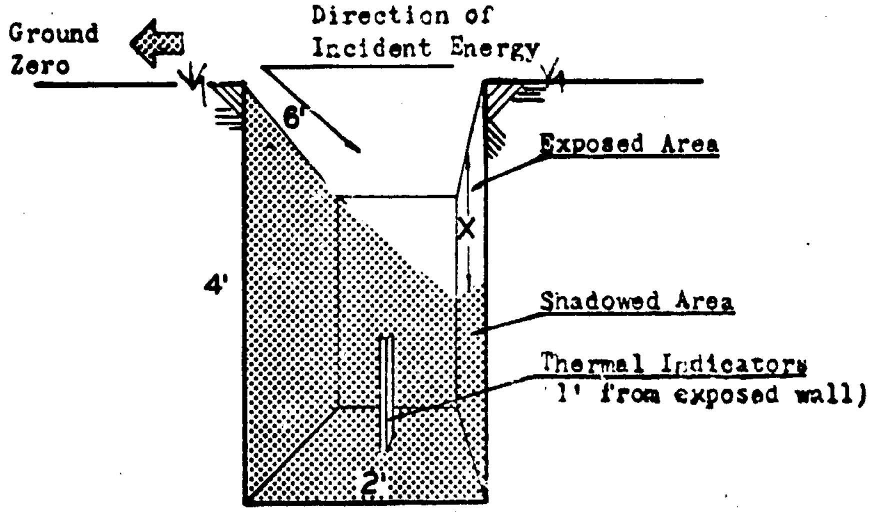
Figs. 13.1 to 13.12 give the fraction of incident energy within the foxhole as a function of distance from exposed wall at a particular depth or as a function of depth at a particular distance from the exposed wall.

13.3 CALORIMETERS

In each case, the calorimeters were placed in the foxholes such that direct comparison of the total energy as measured by the calorimeters and the passive indicators could be made. The reflected thermal energy, as measured by the calorimeters along with their position in the foxholes, is given in Tables 13.1 and 13.2 and Figs. 13.14 and 13.15.

13.4 MAGNITUDE OF INTERREFLECTION

Figure 13.13 gives the fraction of incident energy as a function of distance from the directly exposed wall for the 3 ft depth in the foxhole. In this emplacement, all of the walls (except that which was directly exposed) were coated with a low reflectance, flat black paint.



Foxhole Cross Section

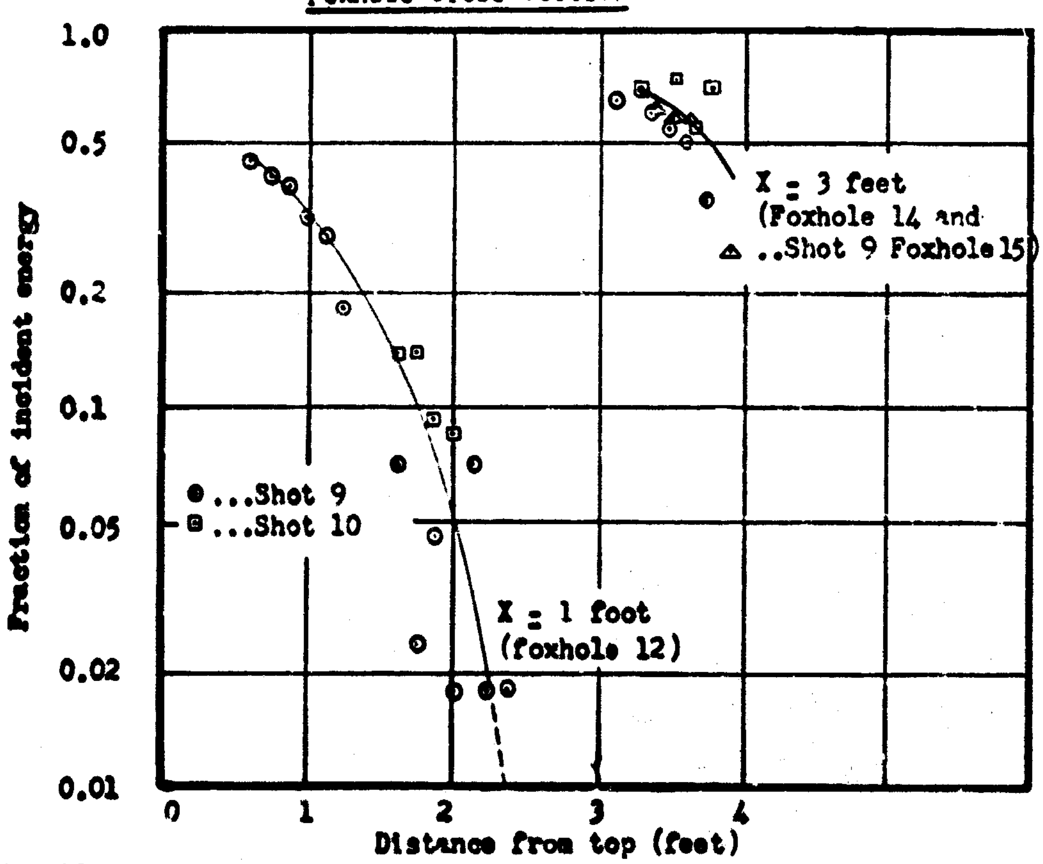
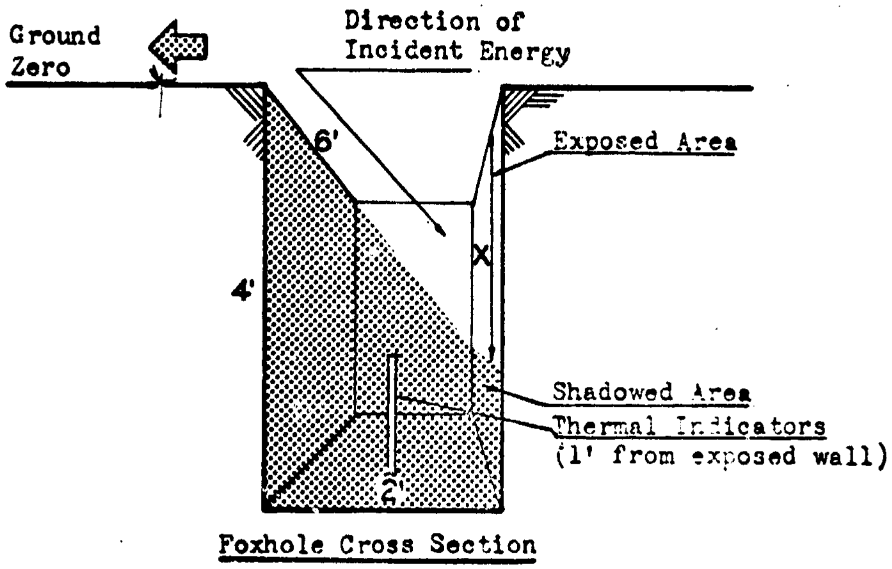


Fig. 13.1 Fraction of Incident Thermal Energy as a Function of Depth in Foxhole



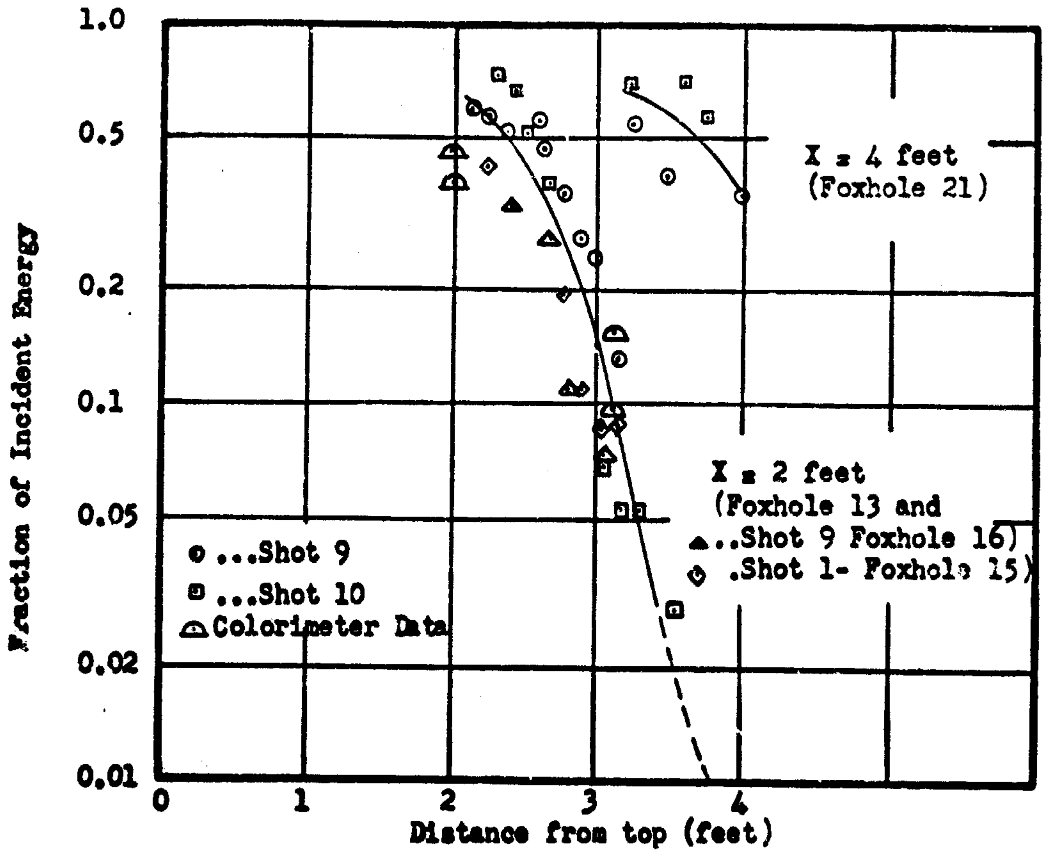
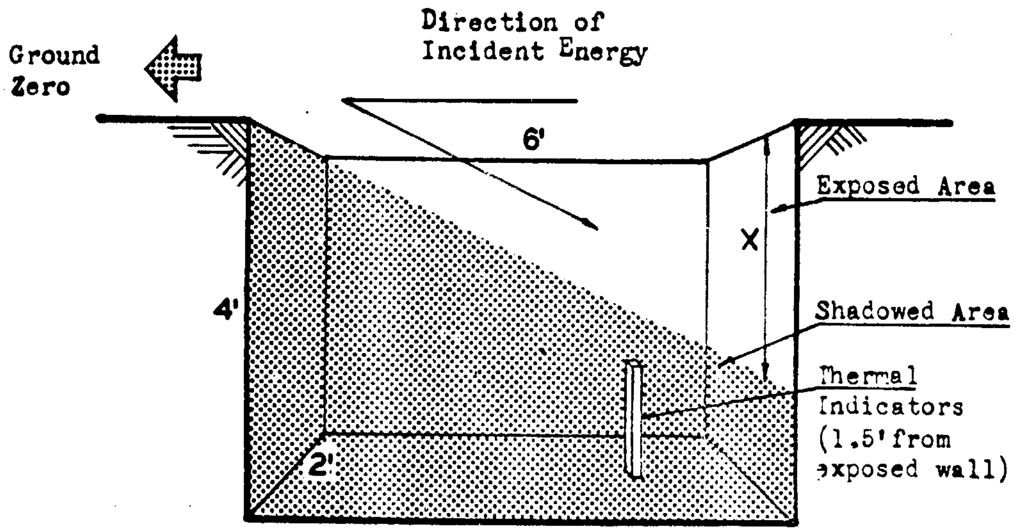


Fig. 13.2 Fraction of Incident Thermal Energy as a Function of Depth in Foxhole



Foxhole Cross Section

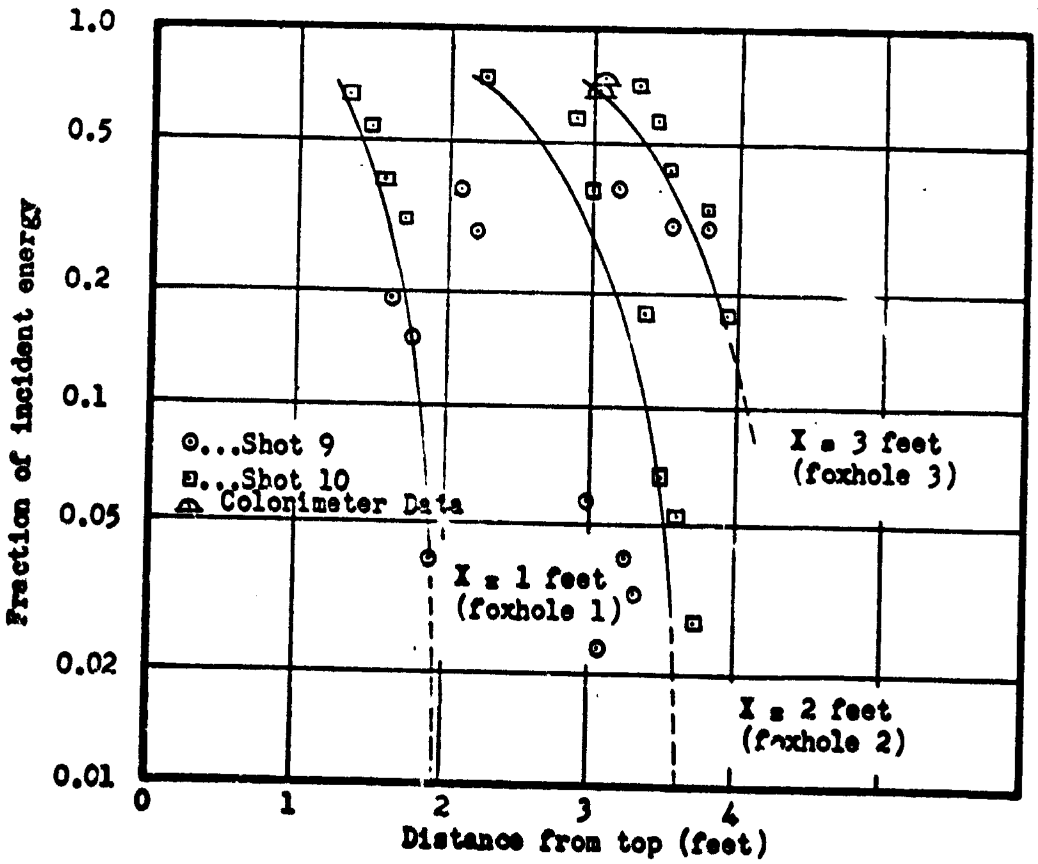


Fig. 13.3 Fraction of Incident Thermal Energy as a Function of Depth in Foxhole

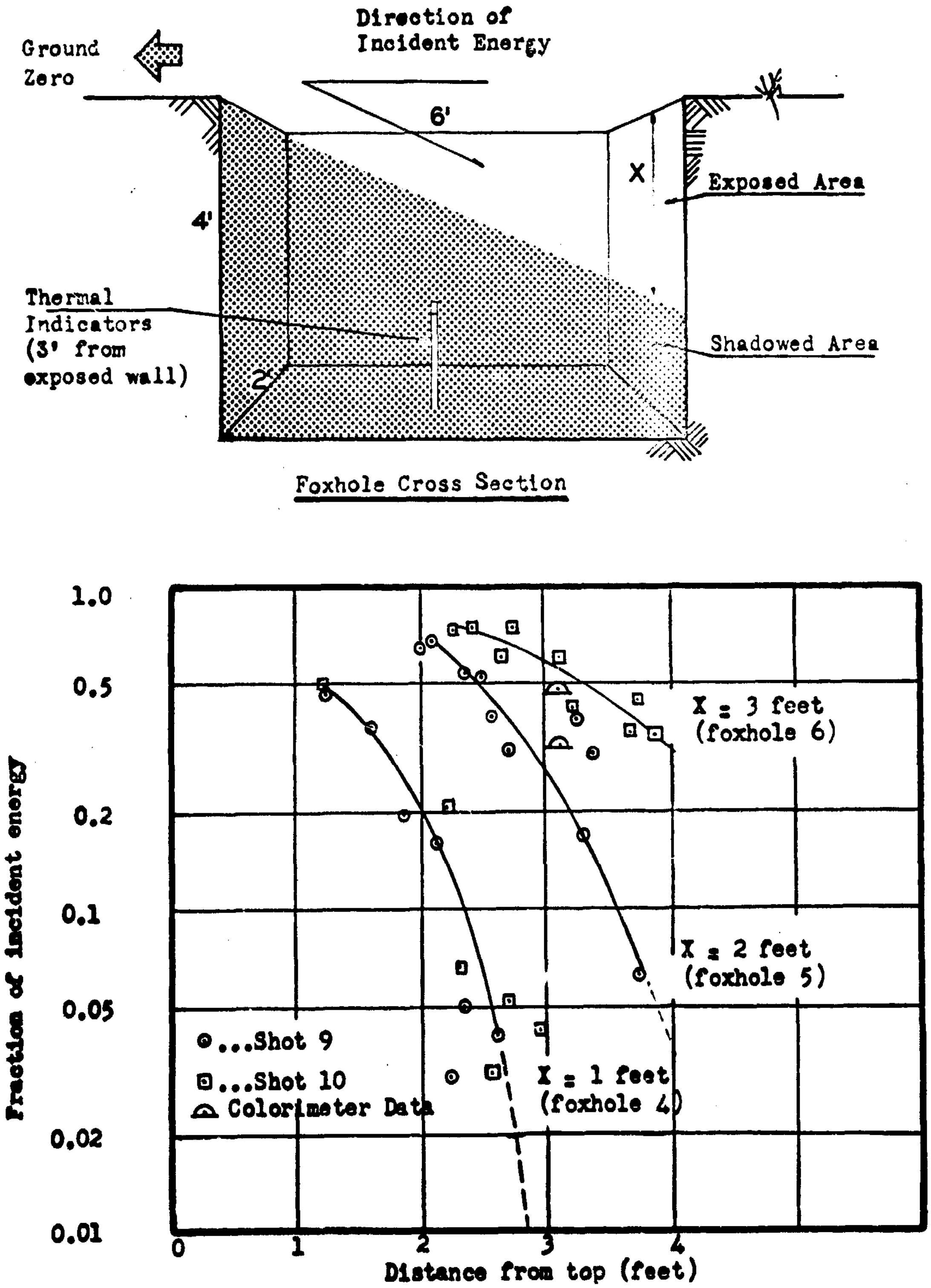
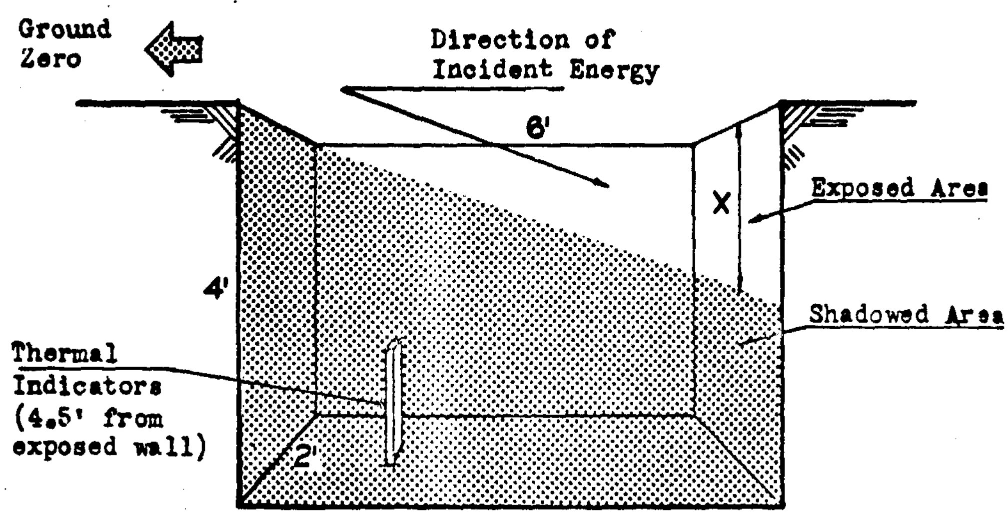


Fig. 13.4 Fraction of Incident Thermal Energy as a Function of Depth in Foxhole



Foxhole Cross Section

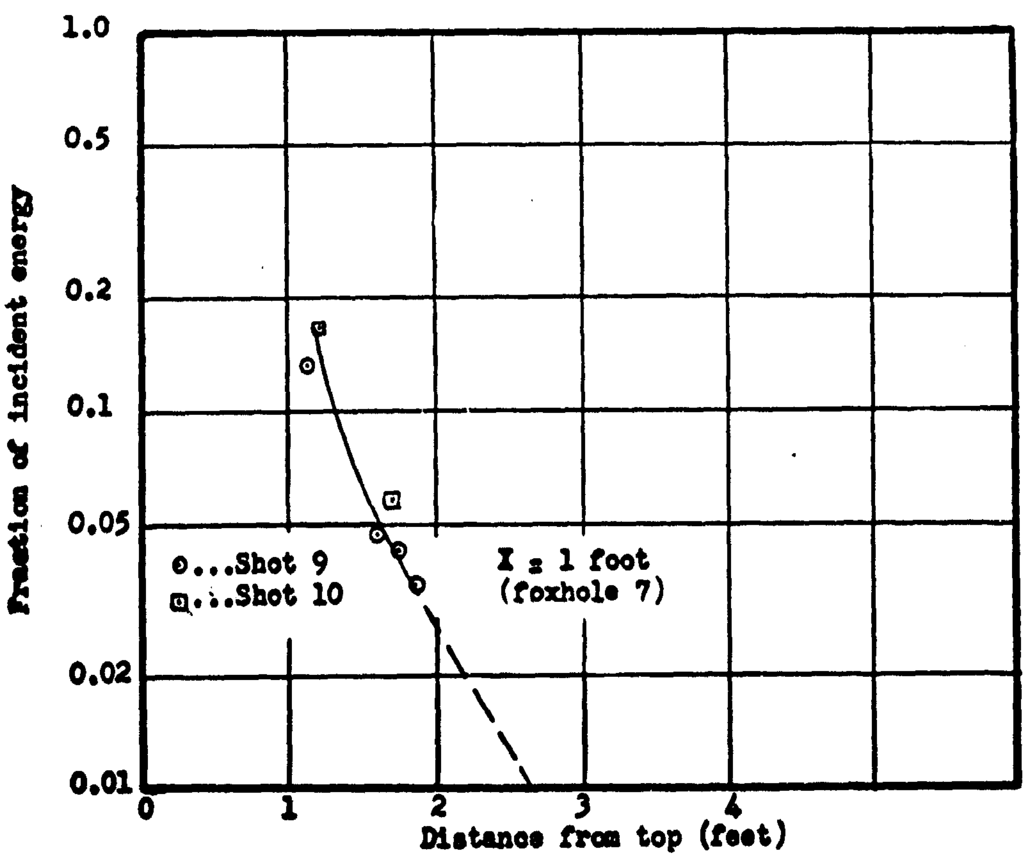
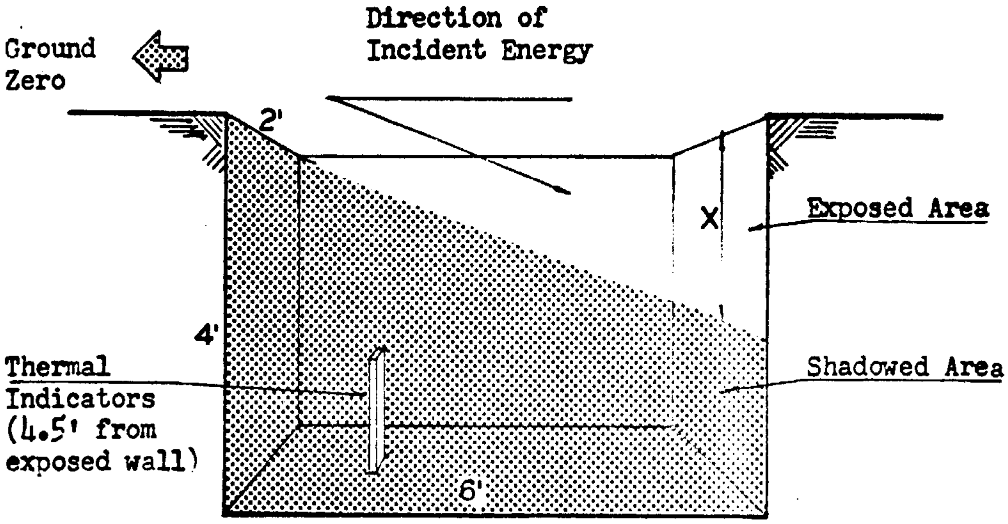


Fig. 13.5 Fraction of Incident Thermal Energy as a Function of Depth in Foxhole



Foxhole Cross Section

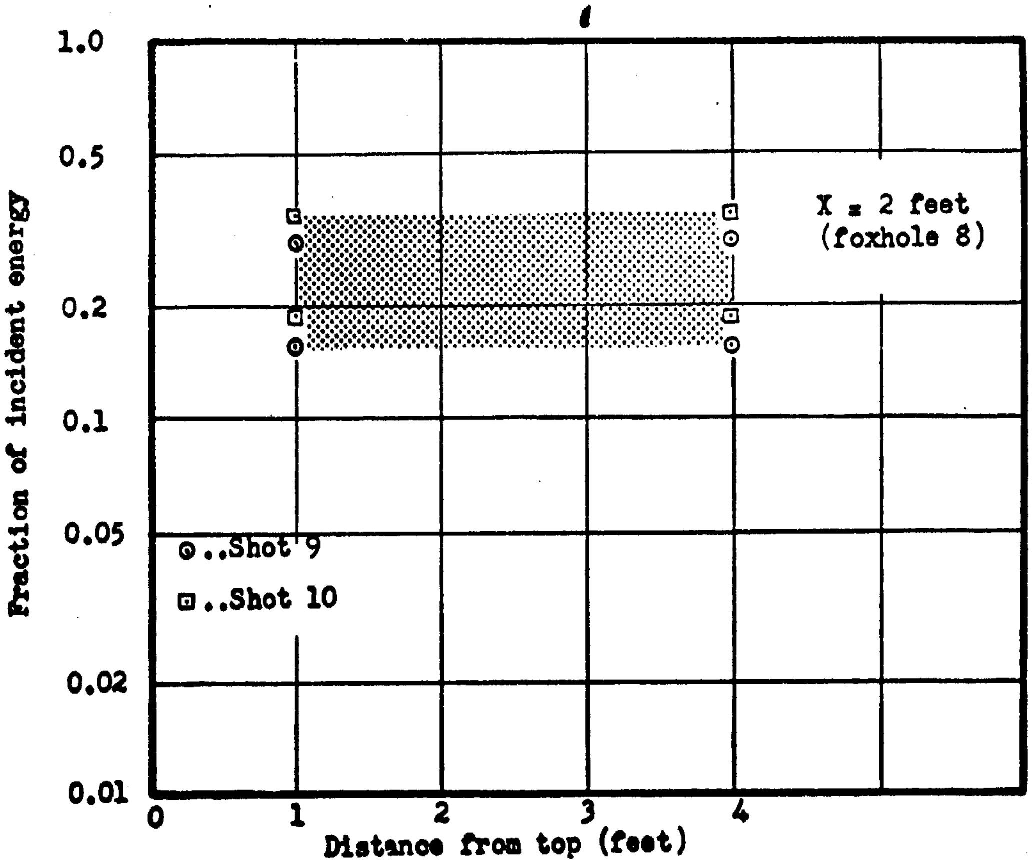
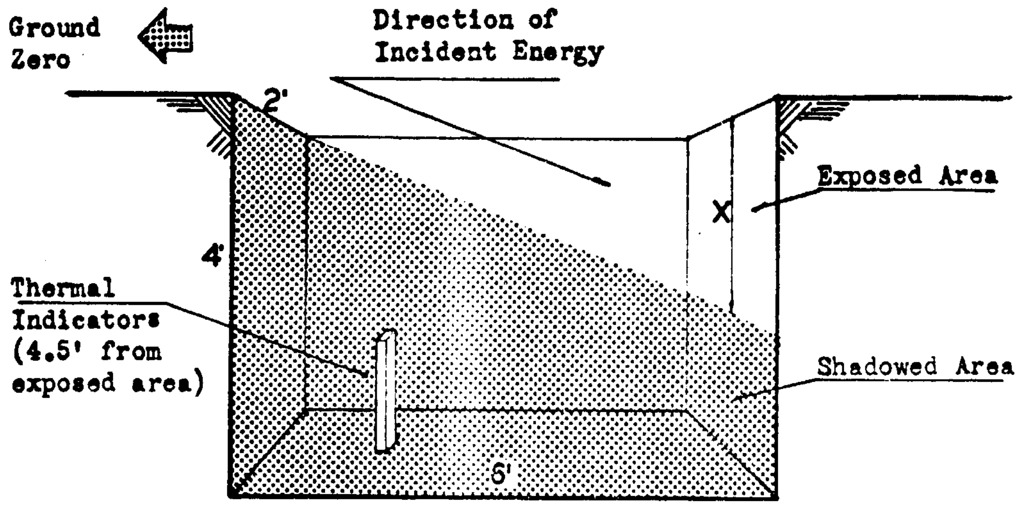


Fig. 13.6 Fraction of Incident Thermal Energy as a Function of Depth in Foxhole



Foxhole Cross Section

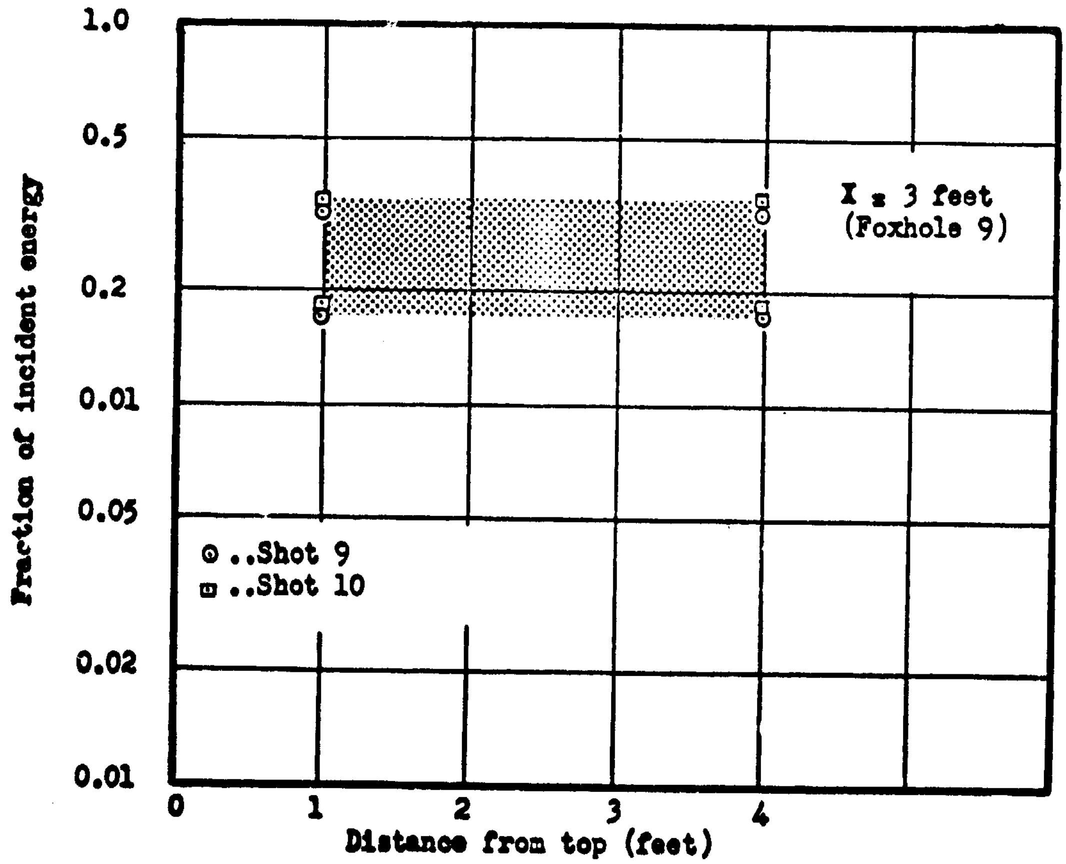


Fig. 13.7 Fraction of Incident Thermal Energy as a Function of Depth in Foxhole

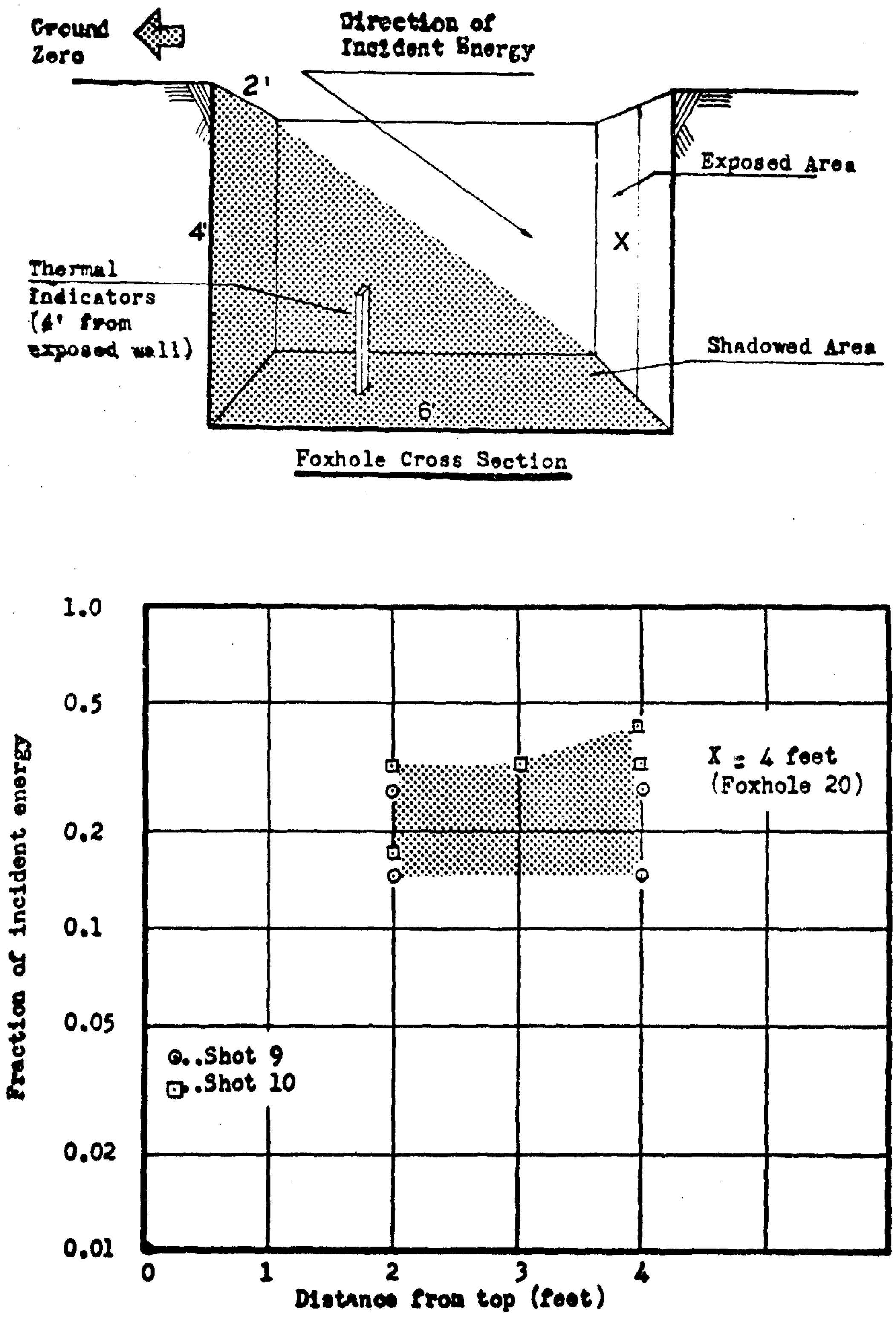


Fig. 13.8 Fraction of Incident Thermal Energy as a Function of Depth in Foxhole

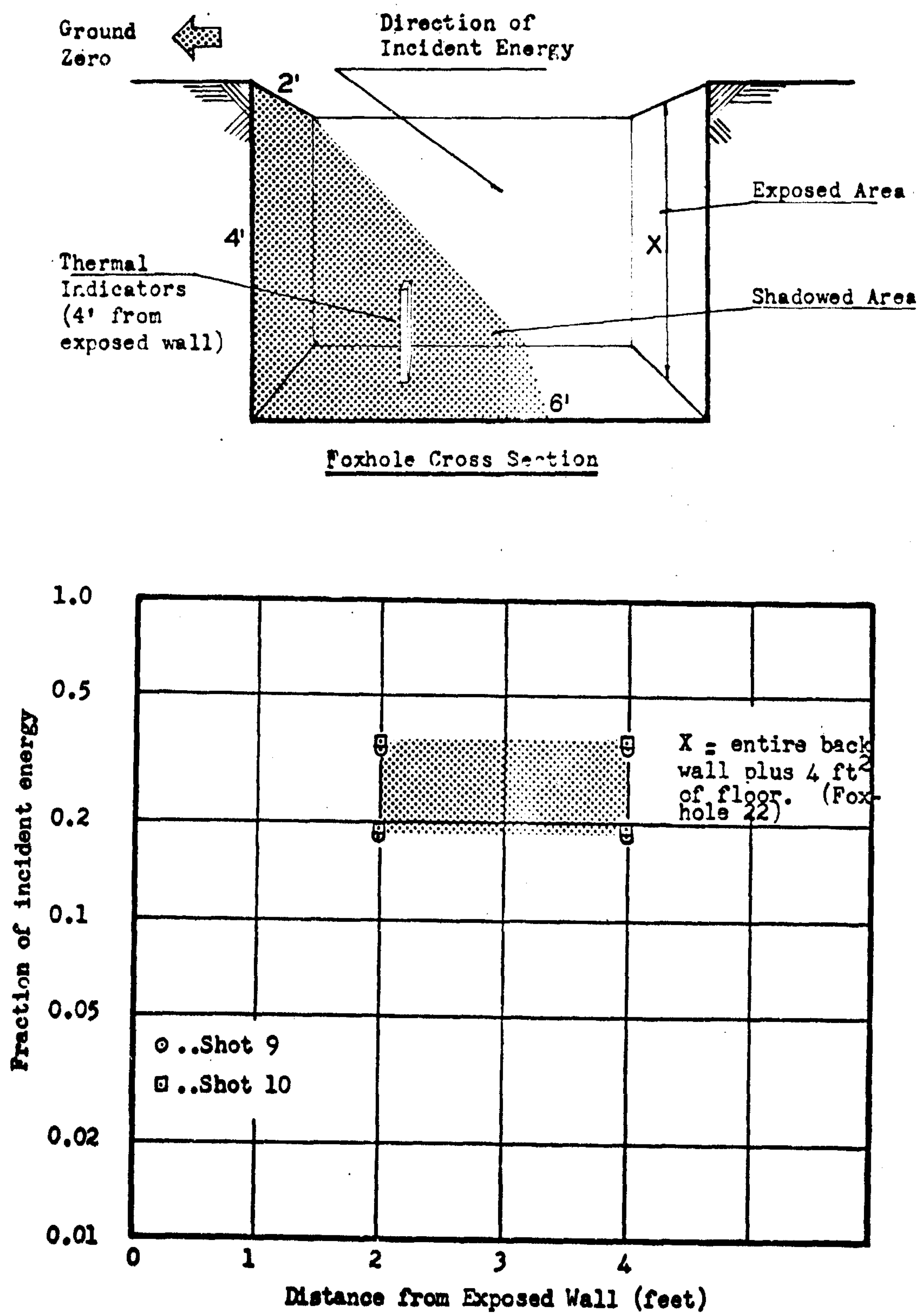
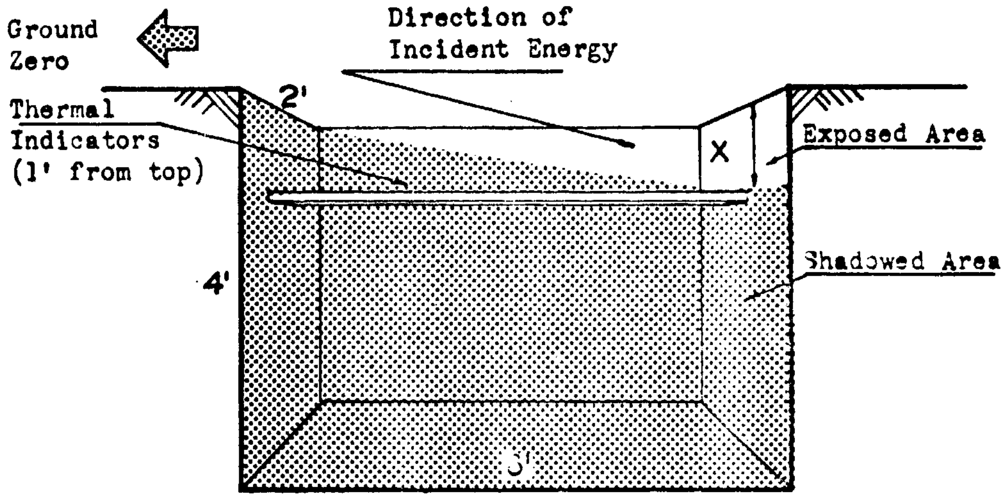


Fig. 13.9 Fraction of Incident Thermal Energy as a Function of Depth in Foxhole



Foxhole Cross Section

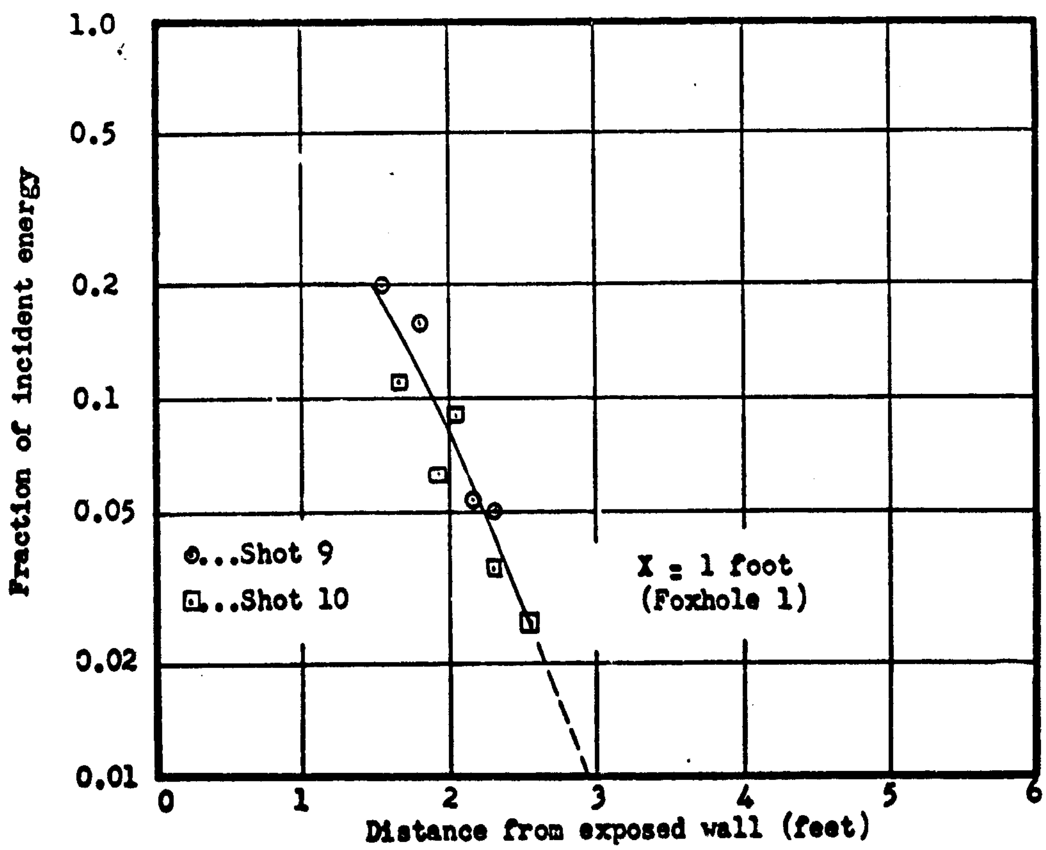
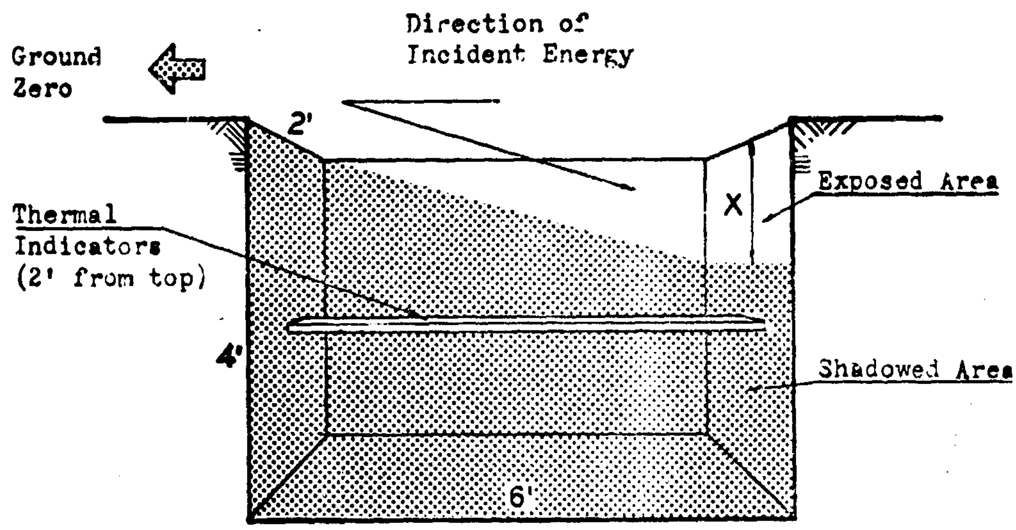


Fig. 13.10 Fraction of Incident Thermal Energy as a Function of Distance from Exposed Wall



Foxhole Cross Section

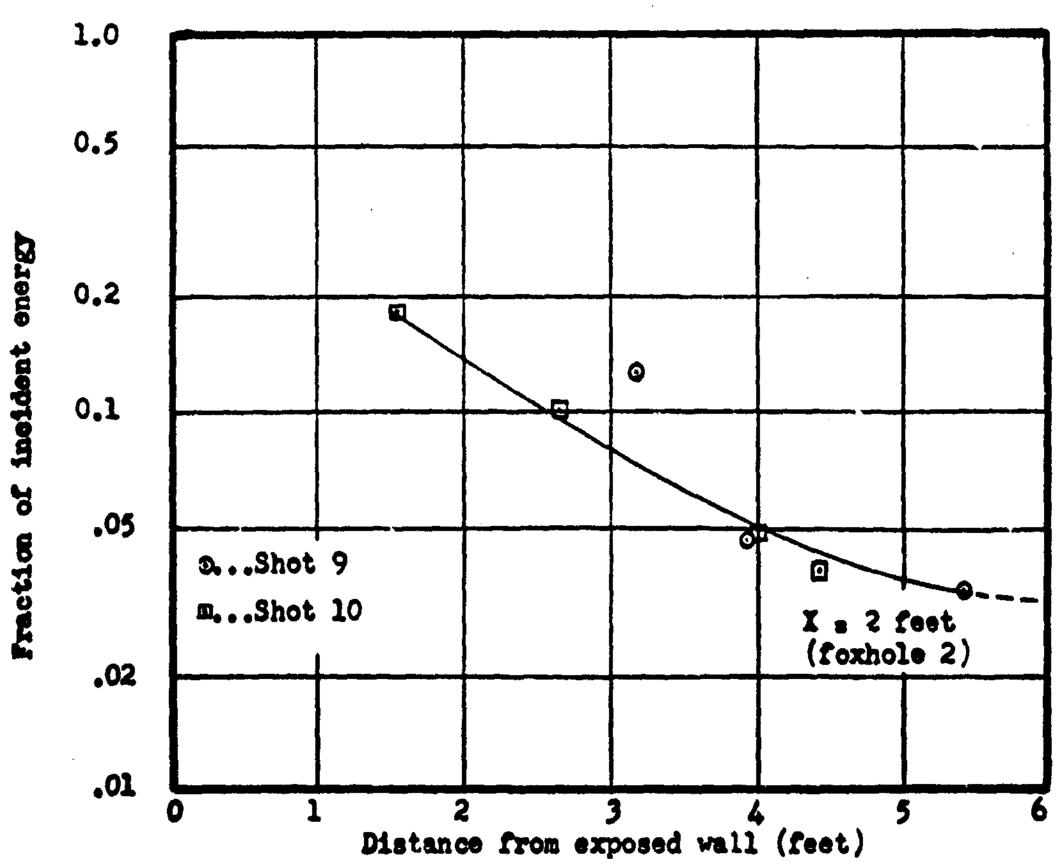
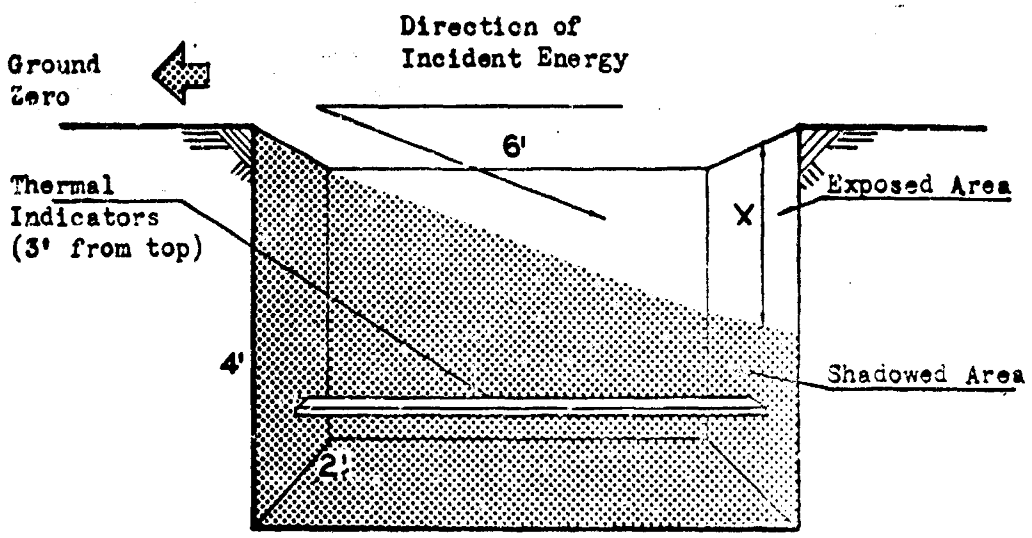


Fig. 13.11 Fraction of Incident Thermal Energy as a Function of Distance from Exposed Wall



Foxhole Cross Section

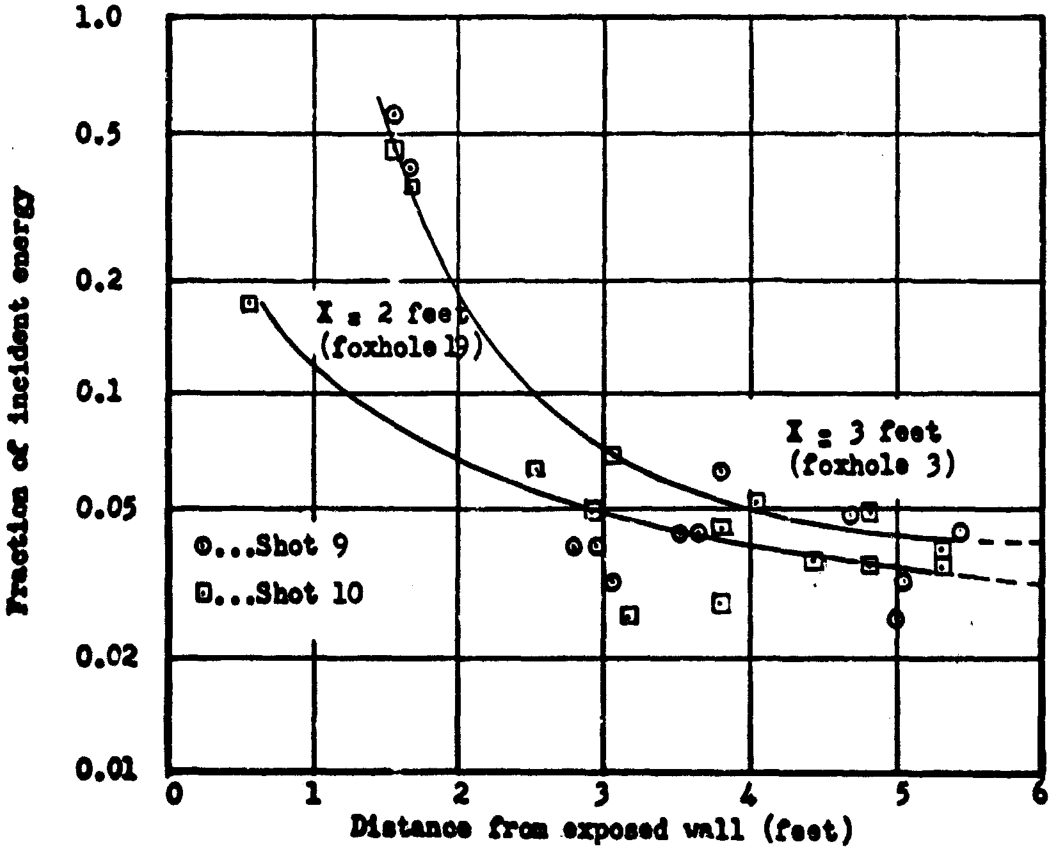
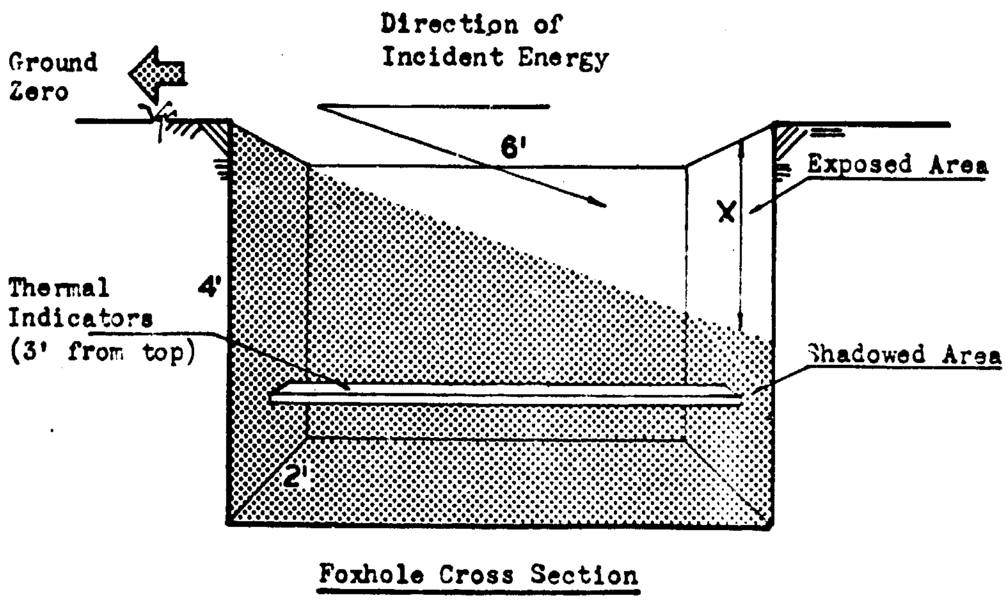


Fig. 13.12 Fraction of Incident Thermal Energy as a Function of Distance from Exposed Wall



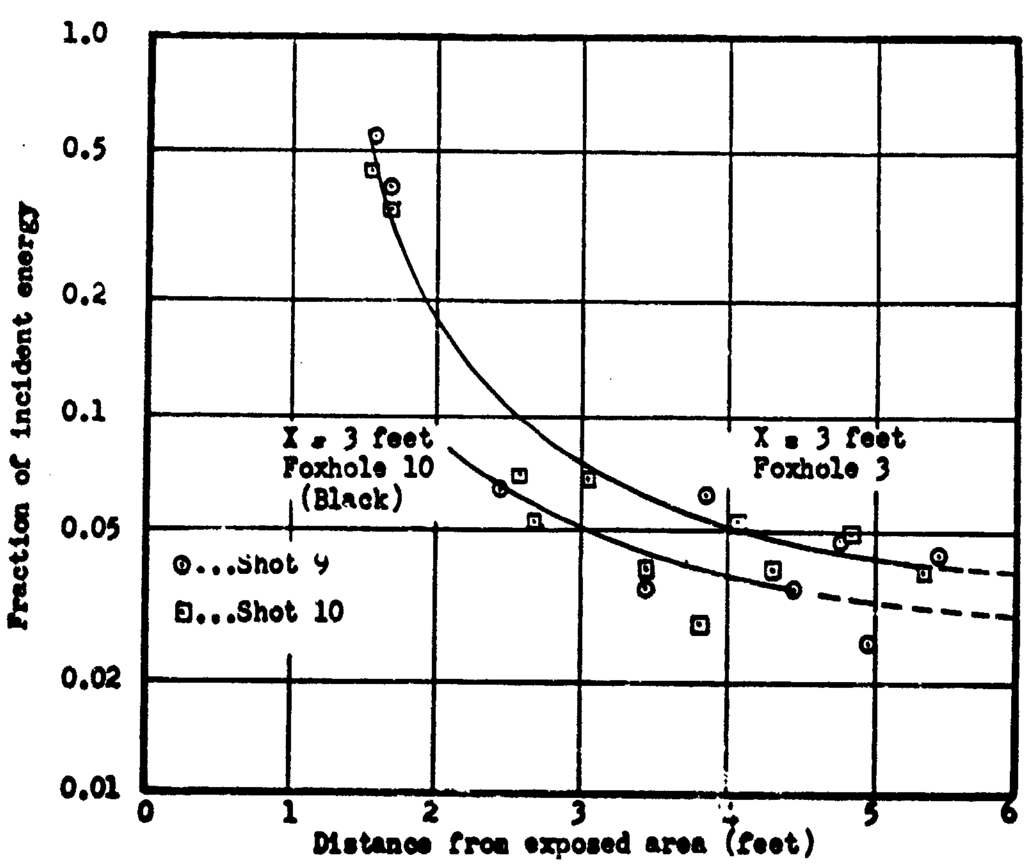


Fig. 13.13 Fraction of Incident Thermal Energy as a Function of Distance from Exposed Wall

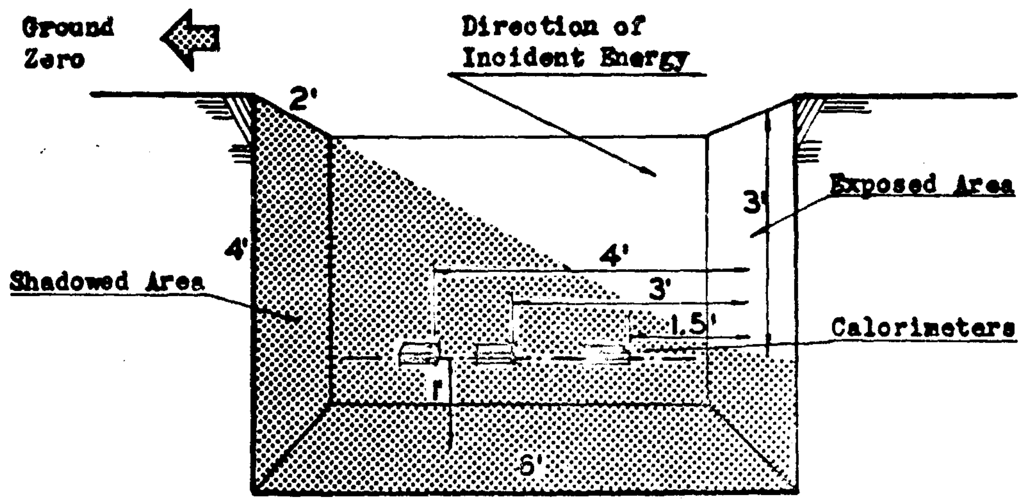


Fig. 13.14 Foxhole Cross Section

TABLE 13.1 - Calorimeter Results

Shot	Distance From Top	Distance From Exposed Wall	Energy	Fraction	Correction Factor	Corrected Fraction
9	3'	1.5'	8.85	.402	1.76	.708
	3'	3.0'	4.04	.183		.322
	3'	4.0'	3.70	.168		.296
	3'	1.5'	5.20	.452	1.64	.741
	3'	3.0'	3.36	.292		.479
	3'	4.0'	2.04	.170		.279

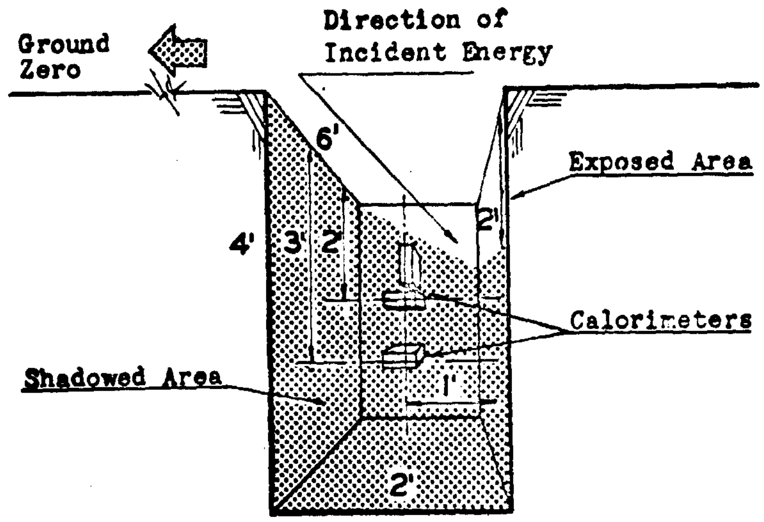


Fig. 13.15 Foxhole Cross Section

TABLE 13.2 - Calorimeter Results

Shot	Distance From		Energy	Fraction	Correction Factor	Corrected Fraction
	Top	Exposed Wall				
9	2	1	3.37	.280	1.46	.409
	3	1	1.35	.112		.164
	*2	1	2.12	.177		.258
10	2	1	1.54	.257	1.74	.447
	3	1	0.32	.053		.092
	*2	1	1.04	.173		.301

* Calorimeters facing directly upward.

CHAPTER 14

DISCUSSION

14.1 GENERAL

The data as given in Figs. 13.1 to 13.12 enable the prediction of the reflected thermal energy distribution in a foxhole for the following conditions:

1. Long (6 ft) edge parallel to a radial line from the bomb and 2, 4, 6, or 8 ft^2 of the back wall directly exposed which corresponds to the direct energy incident 1, 2, 3, or 4 ft, respectively, down the back wall.

2. Long (6 ft) edge parallel to a radial line from the bomb and 8 ft^2 of the back wall plus 4 ft^2 of the floor directly exposed. This was considered the most extreme exposure conceivable, still permitting a man to crouch in the shadowed portion of the foxhole.

3. Long (6 ft) edge perpendicular to a radial line from the bomb and 6, 12, 18, or 24 ft^2 of the back wall directly exposed which corresponds to the direct energy incident 1, 2, 3, or ft respectively down the back wall.

14.2 ANALYSIS OF RESULTS

14.2.1 Vertical Receivers

In those foxholes in which the receivers were oriented vertically with respect to the foxhole, the data curves for each receiver position are characterized by the same general shape. See Appendix D. This is evident in all but Fig. 13.6 to 13.9, which are the curves for the receiver 4.0 ft or 4.5 ft from the directly exposed wall. For these cases, the apparent discrepancy can be resolved by considering the fact that the indicators when placed along a line at this distance from the directly exposed wall are such that the distance between the directly exposed wall and the receivers is only slightly changed as the receiver depth is increased to 4 ft. As a consequence, the energy at the receivers varied slightly, and the data could only be represented as a band.

For each other receiver location (1 ft, 1.5 ft, or 3 ft from the directly exposed wall), the curves have a similar shape; and the

author feels that, when any other intermediate area is exposed, the energy distribution may be obtained for these conditions by careful and discreet interpolation.

The location of each individual curve indicates that the position of the receiver relative to the directly exposed source (wall) is the main factor in determining the energy received by the receivers. Of lesser importance, within limits, is the area of source and also the angle of incidence of the direct energy on the source (exposed wall).

14.2.2 Horizontal Receivers

The curves in this case have maximum fractional values near the source which are considerably lower than the case for vertical receivers. They all tend to decrease as distance from the source increases.

When 2 ft^2 of the wall were directly exposed and the receivers were placed along a line 2 ft and 3 ft from the top of the foxhole, there were no indicator reactions capable of being interpreted, which indicates that the energy received in this area was too low to be measured reliably by the passive indicators. However, it may be concluded that the fraction is at least less than 0.0510 when the receivers are 2 ft from the foxhole top, and less than 0.0300 when the receivers are 3 ft from the top.

14.2.3 Calorimeters

It was anticipated that a direct comparison of the calorimetric and passive indicator data could be made. However, since the aperture of the calorimeters used was 90°, and the aperture of the passive indicators was essentially 180°, a direct comparison is not meaningful. The calorimetric results in Table 13.2 are plotted with the passive indicator data in Fig. 13.2. Here, the calorimeter "saw" essentially only 3.14 ft^2 of the exposed wall; while, actually, 12 ft^2 of the wall was exposed. The decrease of measured energy is not directly proportional to these areas, because the source (exposed wall) immediately in front of the receiver contributes a proportionally greater amount of the total received energy.

When the long (6 ft) side is parallel to a radial line from ground zero, there is better correlation. Here, the calorimeters were further from the exposed wall, and they could "see" almost all of the exposed area. The data from these calorimeters are plotted for comparison with the passive indicator results on Figs. 13.3 and 13.4.

Comparison of the calorimeter results as measured in the foxholes with similar calorimeter measurements taken of the direct thermal energy indicates essentially no change in the shape of the thermal pulse. This eliminates the possibility of an excessive amount of dust obscuration or reflection of thermal energy from dust above the emplacement which would negate the passive indicator results.

14.3 MAGNITUDE OF INTERREFLECTION

It was felt that the high reflectance of the foxhole walls would cause some increase in the received energy because of interreflection from one wall to another. In an attempt to measure the magnitude of

this effect, a foxhole was constructed in which the walls (except the one which was directly exposed to the incident radiation) were coated with a low reflectance, flat black paint. Fig. 13.13 gives the data from this foxhole and for a corresponding aluminum lined foxhole, and shows that the energy received by the black foxhole is lower by a factor of approximately 30 per cent when the receivers are relatively far from the source and is lower by a factor of approximately 40 per cent when the receivers are closer to the directly exposed wall. It must be noted that the data are of limited extent and may not be conclusive for other receiver positions.

The actual magnitude of interreflection will depend upon the reflectance of the emplacement walls, increasing as the reflectance increases.

14.4 SCALING

Part of the objective of this test was to provide scaling laws such that the information presented herein would be applicable to all field conditions. Using data from foxholes 11, 15, and 16, and the data from both shots for corresponding foxholes, the average deviation when calculated with respect to the fraction of incident energy is 0.054, and is 0.190 ft when calculated relative to the distance from the top or exposed wall. This indicates that the results, when obtained under different conditions, are reproducible.

14.5 APPLICATION

The reflected thermal energy distribution in a foxhole may be determined for the conditions within the limit of the experiment by using the following formula:

$E = PFI$

E = the desired energy in the foxhole

P = the reflectance of the walls of the foxholes

F = the fraction of incident energy as determined from Figs. 13.1 to 13.12

I = the direct incident energy

The reflectances of some typical soils and materials is given in Table 14.1.

TABLE 14.1 - Reflectances of Typical Materials

Material	Reflectance	Source
Loam, sandy	0.24	1
Earth, moist	0.08	1
Marl, argillaceous	0.16	1
Snow	0.93	1
Yucca Flat sand	approx 0.30	2
Frenchman Flat sand	approx 0.25	2
Pine	0.53	3
Oak	0.35	3
Birch	0.35	3
Walnut	0.23	3

1. Handbook of Chemistry and Physics, Chem. Rubber Pub. Co., 32 ed., pages 2444, 2445.
2. The Thermal and Optical Properties of Nevada Sand, Naval Material Laboratory, May 1952, CONFIDENTIAL.
3. Journal of the Optical Society of America, April 1948.

CHAPTER 15

CONCLUSIONS AND RECOMMENDATIONS

15.1 CONCLUSIONS

The thermal energy distribution in a two-man foxhole can be predicted using the data given in Figs. 13.1 to 13.12 and the methods of scaling shown in Chapter 14.

The data from foxholes 11, 15, and 16 and the data from both shots for corresponding foxholes indicate that scaling to reasonable operational conditions of height of burst, distance from ground zero, and yield is valid.

The thermal energy distribution in foxholes, as well as in other types of emplacements, can be predicted by using the methods, and within the limitations, of Appendix D.

If the reflectance is one third or less, a man will receive less than 10 per cent of the direct thermal radiation if he is in the shadowed portion of his foxhole at least 1 ft below the limit of the direct thermal radiation on the exposed wall.

15.2 RECOMMENDATIONS

It is recommended that this experiment be considered conclusive unless a requirement is shown for the thermal energy distribution in an emplacement of markedly different geometry, such as a case where the directly exposed wall is not perpendicular to a radial line from ground zero, or unless a requirement is shown for data of greater detail or extent.

With its limitations in mind, it is recommended that the method described in Appendix D for determining the energy received in an emplacement be considered for general use.

PART IV

GAMMA RADIATION IN FOXHOLES

CHAPTER 16

INTRODUCTION

16.1 OBJECTIVE

The objective of Part IV of Project 3.9 was to instrument a 2' x 4' x 6' two-man foxhole for prompt gamma radiation such that the angular dependence of the instrumentation is determined.

16.2 BACKGROUND

Under Project 2.6, BUSTER, a series of two-man foxholes were instrumented to measure prompt gamma radiation; and the results were subsequently published in the final report(6). Among the conclusions were: the exposure for troops at the bottom of foxholes would be about 12 per cent of that received by unprotected troops in the same location; air-scattered gamma radiation contributed from 80 to 90 per cent of the total intensity at the bottom of the foxhole. This information was based on film badges (the prompt gamma radiation instrumentation) which were placed vertically with respect to the foxhole.

Shortly prior to UPSHOT-KNOTHOLE, the question was posed as to whether the orientation of the film badges in the foxholes would markedly change the concepts of fortification protection described in the Project 2.6, BUSTER report. To answer this question, one two-man foxhole was instrumented with film badges which were placed vertically, horizontally, and at a 45° angle with respect to the foxhole.

16.3 DISCUSSION

The basis of this experiment was to justify the method of instrumentation and the assumptions used in Project 2.6, BUSTER. Therefore, this experiment is primarily concerned with the angular dependence of film badges, rather than the protection afforded by field fortifications.

Theoretically, the response of a film badge which is placed at various angles to parallel gamma radiation will depend upon the angle of incidence of the radiation and should follow the familiar cosine relation

$$I_\theta = I_n \cos \theta$$

where I_n is the amount of incident radiation measured normal to the direction of incident radiation, the θ (called the angle of incidence) is the angle between the direction of the incident radiation and the normal to the badge; and I_θ is the amount of incident radiation measured at the angle θ. Thus, as θ increases from 0° to 90°, the value of I_θ will decrease from a maximum equal to I_n to zero.

It was discovered in BUSTER that the majority (80-90 per cent) of the radiation received at the bottom of a foxhole could be attributed to that which is scattered, and that this radiation comes essentially from the top of the foxhole. Accordingly, most of the radiation received by the films near the bottom of the foxhole was at a high angle of incidence. This, it was felt, would cause the films to read too low. Ellery Storm of Los Alamos Scientific Laboratory made an investigation and concluded that an average correction factor of 1.5 would compensate for a high angle of incidence(24). Further speculation about this effect was made; and it was postulated that the radiation values obtained in BUSTER may be too low, even though the 1.5 correction factor is applied. The objective of this experiment was to investigate this assumption.

CHAPTER 17

INSTRUMENTATION

17.1 FILM BADGES

Standard dosimeter film packets using DuPont types 554 insensitive and 558 insensitive films were used as the gamma radiation detectors. The type 554 insensitive film was used to detect gamma radiation intensities to about 200 roentgens, while the type 558 insensitive was utilized to detect gamma radiation intensities to about 1000 roentgens.

For field exposure, the badges were mounted in National Bureau of Standards film holders.

17.2 CALIBRATION

Since the film badges were placed horizontally, vertically, and at a 45° angle with respect to the foxhole, it was necessary to calibrate the films at a series of angles of incidence. This was accomplished by using a Co_{60} source and rotating the films to the desired angle. It was determined that the calibration curves as obtained from the Co_{60} source were sufficiently accurate to be used with no further modification for the radiation range of interest in this test.

Comparison of the calibration curves indicated that the angular dependence of the exposure of the badge was not as critical as would be postulated on the basis of the cosine law. The calibration data were not of sufficient detail to verify any relationship between the exposure of the film and the angle of incidence of the radiation.

It was felt that the materials of the NBS holder tend to scatter and, to some extent, attenuate the incident radiation.

17.3 TEST SITE

One foxhole, 4000 ft from expected ground zero, along the East-West blast line was utilized for this experiment. The film badges were placed, numbered, and oriented as shown in Figs. 17.1 and 17.2.

Shot 9 was used for the exposure.

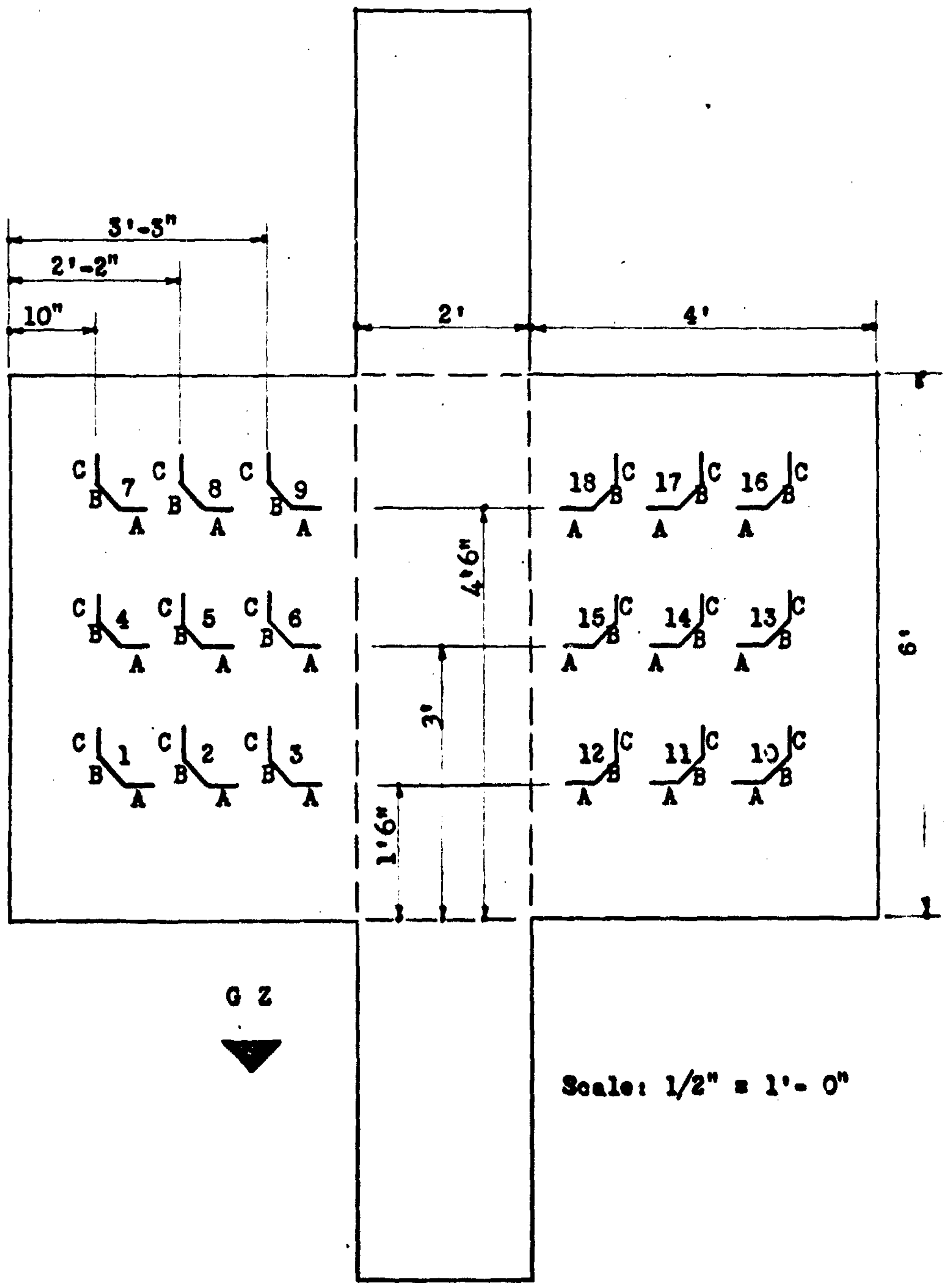


Fig. 17.1 Numbering of Film Badge Locations

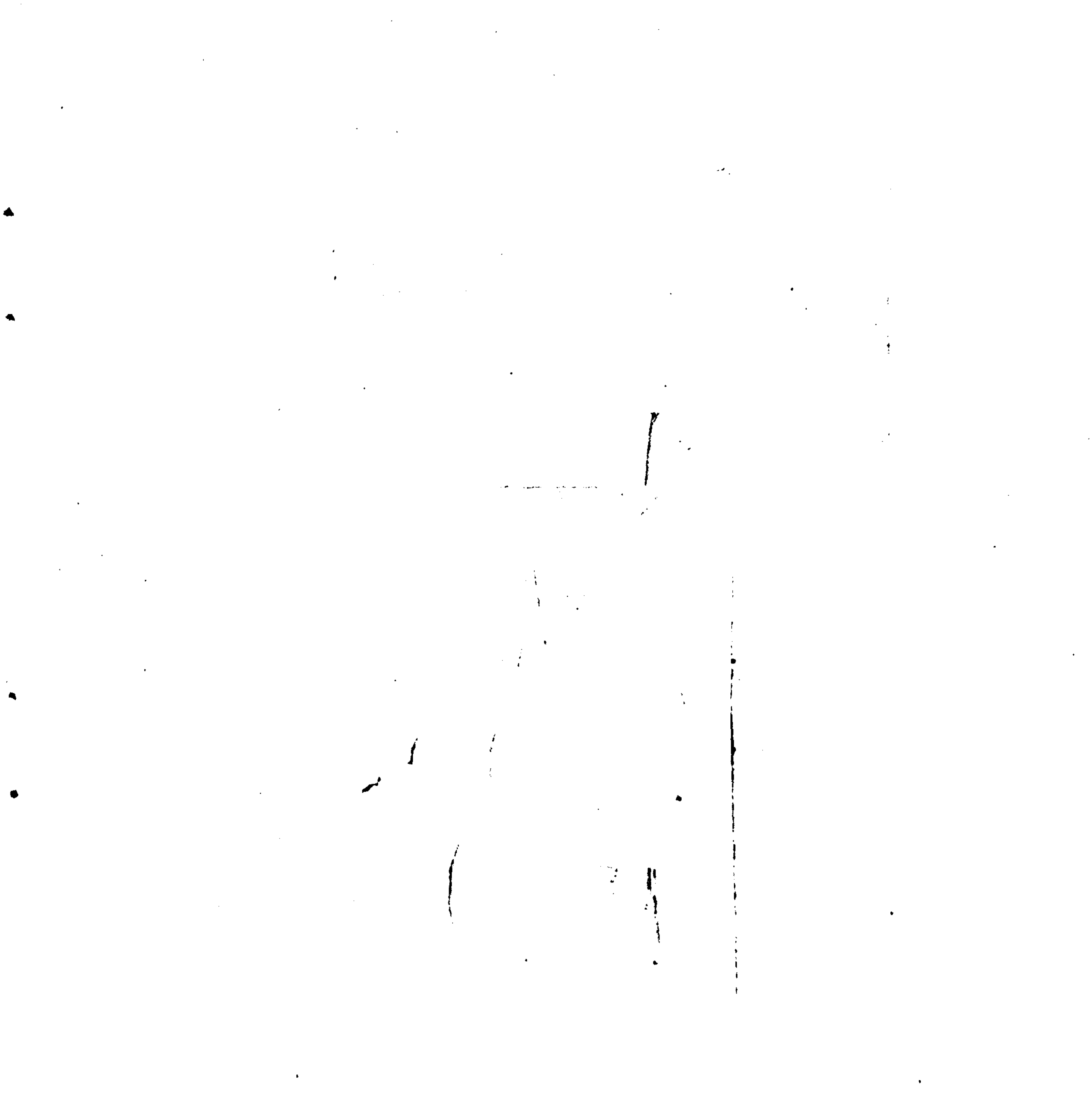


Fig. 17.2 Photograph of Foxhole

CHAPTER 18

RESULTS

18.1 METHODS OF ANALYSIS

The film badges used during BUSTER were placed vertically with respect to the foxhole and calibrations were made with the film placed at a zero degree angle of incidence (the film was perpendicular to the incident energy). In order to obtain a direct comparison, all of the films used in this test which were placed in position A (vertical with respect to the foxhole) were read from calibration curves made at a zero degree angle of incidence.

It was determined during BUSTER that 80-90 per cent of the radiation received near the foxhole bottom was scattered in from the top. Therefore, the films placed in positions B (45° angle) and C (horizontal) in groups 2, 3, 6, 9, 11, 12, 15, and 18 effectively received most of the incident radiation at an angle that is formed approximately by a line drawn from the upper front edge of the foxhole to the film and the normal to the film. Thus, each of these films was characterized by an angle of incidence. Calibration curves for these angles were drawn and the amount of radiation was obtained. These data, and the per cent difference between positions A and B and A and C, are given in Tables 18.1 and 18.2.

It was felt that the remaining groups received essentially all of their radiation directly, i.e., unscattered. Calibration curves obtained at the angles of incidence on the film of the direct radiation from the bomb were used to obtain the radiation values for positions B and C. Position A was evaluated as discussed earlier in this chapter. These data, and the per cent difference between positions A and B and positions A and C are given in Tables 18.3 and 18.4. The overall average per cent difference between positions A and B and positions A and C is given in Table 18.5.

All of the above data have been corrected to give the radiation value had each film of a group (horizontal, vertical, and at a 45° angle) been at exactly the same point.

18.2 DISCUSSION OF RESULTS

Position A was chosen as the basis for comparison in Tables 18.1 to 18.5, because this orientation was used during BUSTER. It was necessary to obtain a direct comparison between film badge readings obtained as they were during BUSTER and film badge readings taken at other orientations during this test.

Calibration of the film badges at the angles and by the methods described above provides a direct comparison between data which have been obtained in the most accurate manner available and the data which are in question.

It can be noted by an investigation of Tables 18.1 to 18.4 that there is little significant difference between the radiation values of a group whether obtained horizontally, vertically, or at a 45° angle. This difference becomes even less significant when the 20 per cent error of the film is considered. There is a tendency, however, for the radiation values obtained from the horizontal and 45° angle film badges to be slightly higher than those obtained from the vertical film badge.

TABLE 18.1 - Data from Film Badges Receiving Scattered Radiation

Film Type - 554 Insensitive

Position	Exposure (Roentgens)			Difference Between A and B(%)	Difference Between A and C(%)
	A	B	C		
2	26	16	23	38	12
3	15	16	17	7	13
6	19	23	19	21	0
9	23	22	33	4	43
11	33	38	40	15	21
12	15	18	16	20	7
15	28	32	28	12	0
18	80	67	65	16	19

TABLE 18.2 - Data from Film Badges Receiving Scattered Radiation

Film Type - 558 Insensitive

Position	Exposure (Roentgens)			Difference Between A and B(%)	Difference Between A and C(%)
	A	B	C		
2	29	25	42	14	45
3	12	15	15	25	25
6	17	23	24	35	41
9	22	28	33	27	50
11	34	47	48	38	41
12	15	19	17	27	13
15	35	33	47	6	34
18	67	68	84	1	25

TABLE 18.3 - Data from Film Badges Receiving Direct Radiation

Film Type - 554 Insensitive

Position	Exposure (Roentgens)			Difference Between A and B(%)	Difference Between A and C(%)
	A	B	C		
1	143	239	90	67	37
4	175	169	173	3	1
5	36	40	46	11	28
7	195	201	194	3	1
8	55	56	58	2	5
10	190	186	199	2	5
13	225	220	240	2	7
14	81	94	90	16	11
16	225	250	260	11	16
17	168	161	181	4	8

TABLE 18.4 - Data from Film Badges Receiving Direct Radiation

Film Type - 558 Insensitive

Position	Exposure (Roentgens)			Difference Between A and B(%)	Difference Between A and C(%)
	A	B	C		
1	126	166	175	32	39
4	153	-	199	0	30
5	40	62	54	55	35
7	161	185	220	15	37
8	52	66	68	27	31
10	182	225	225	24	24
13	300	245	260	18	13
14	82	93	100	13	22
16	270	250	310	7	15
17	152	230	172	51	13

TABLE 18.5 - Overall Average Per Cent Difference

Film	Average Percent Difference Between A and B	Average Percent Difference Between A and C
554 Insensitive	14	13
558 Insensitive	24	30

CHAPTER 19

CONCLUSIONS AND RECOMMENDATIONS

19.1 CONCLUSIONS

The angular orientation of film badges used to measure the gamma radiation in a foxhole is not a critical factor in determination of the total dose.

19.2 RECOMMENDATIONS

It is recommended that the angular orientation of film badges be considered not to affect the conclusions of Project 2.6, BUSTER.

APPENDIX A

PLAN OF ALL PROJECT 3.9 EMPLACEMENTS

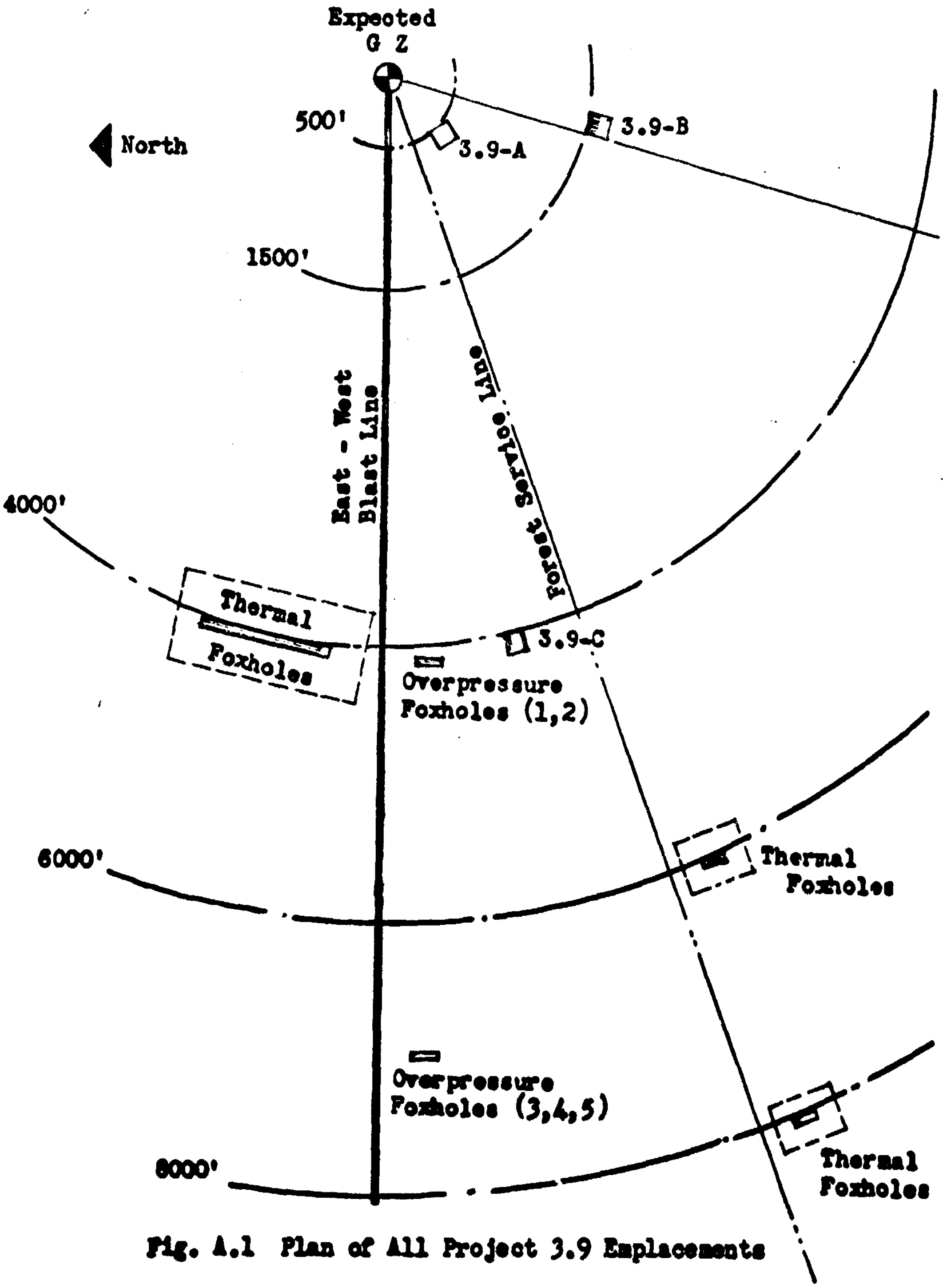


Fig. A.1 Plan of All Project 3.9 Emplacements

APPENDIX B – DISTRIBUTION OF STRUCTURES IN TEST AREAS

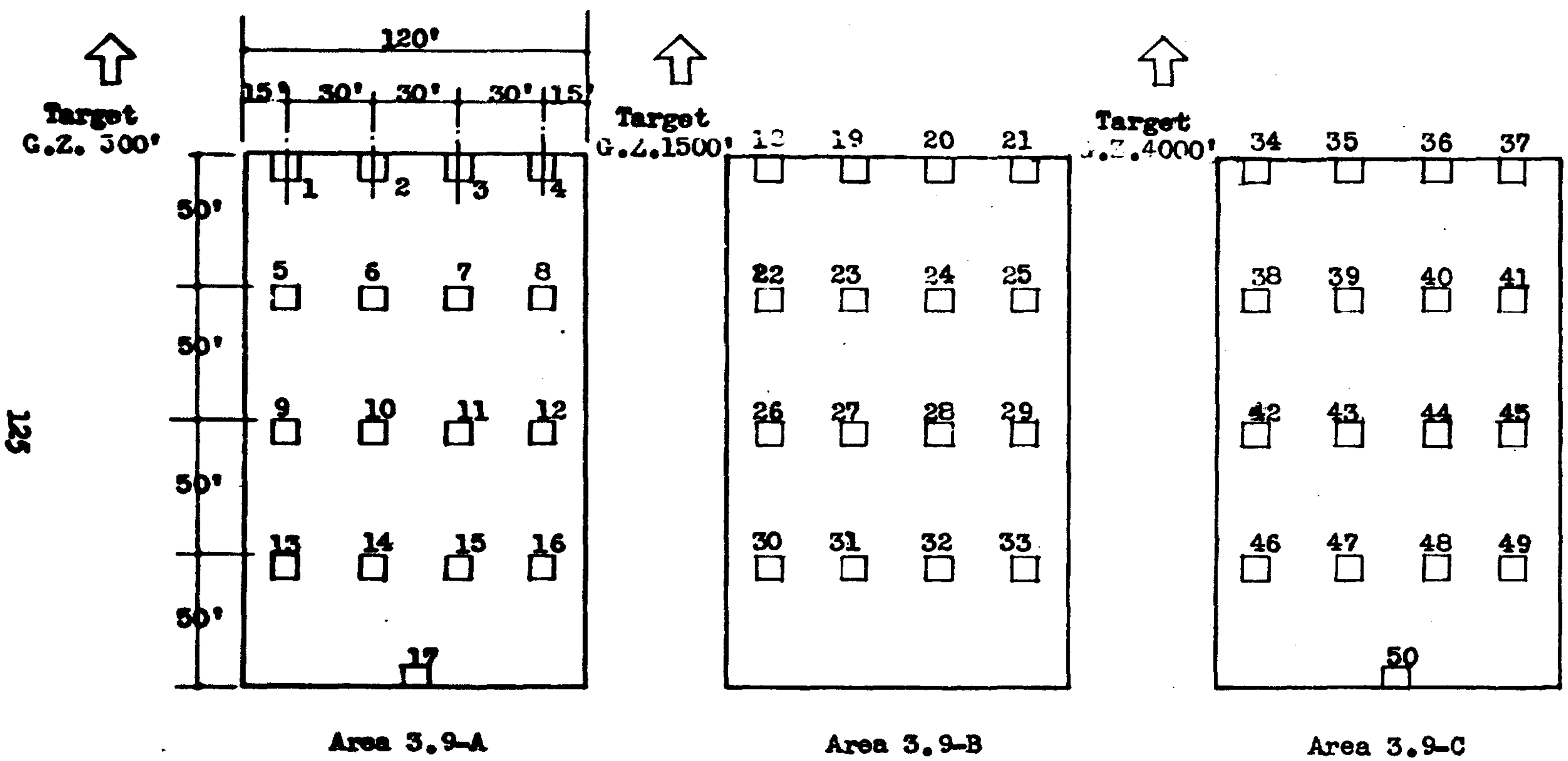


Fig. B.1 Distribution of Structures in Test Areas

APPENDIX C - PRESHOT AND POSTSHOT PHOTOGRAPHS OF TEST STRUCTURES

Fig. C.1 Fortification No. 1, before Shot 9

Fig. C.2 Fortification No. 1, after Shot 9

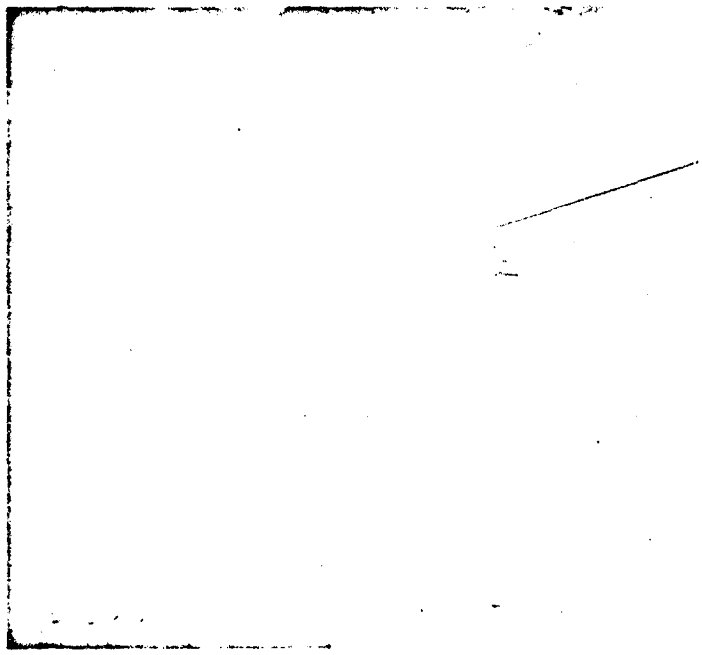


Fig. C.3 Fortification No. 1, after Shot 9

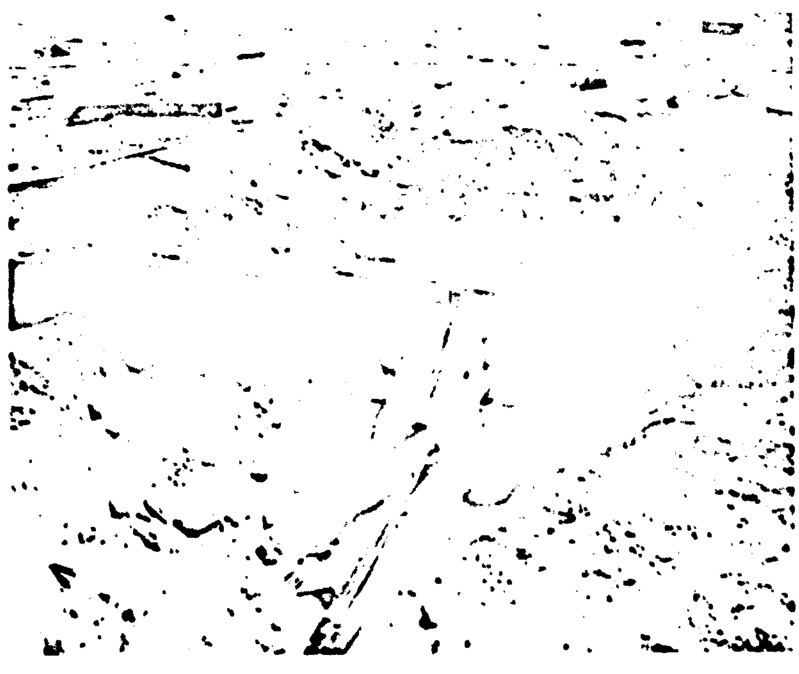


Fig. C.4 Fortification No. 1, after Shot 10

Fig. C.5 Fortification No. 1, after Shot 10

Fig. C.6 Fortification No. 1, after Shot 10

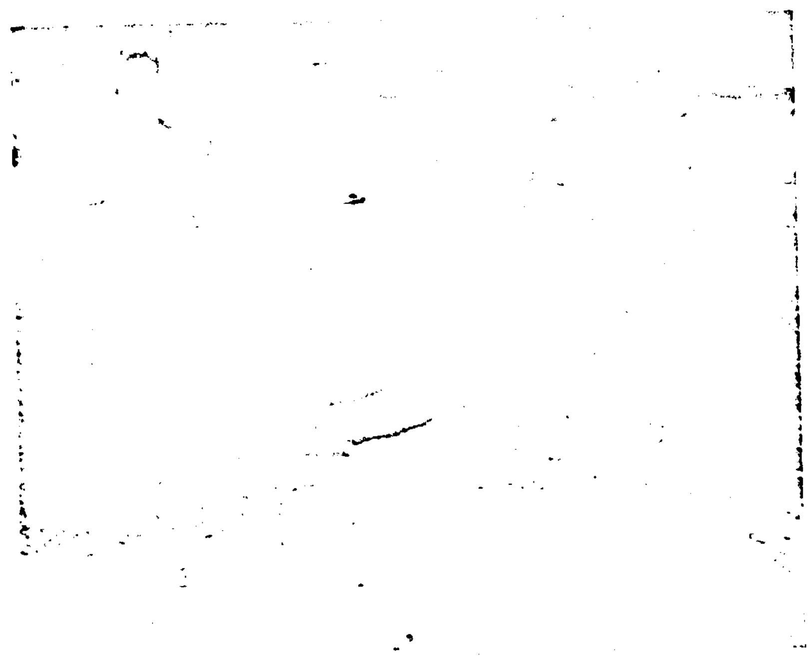


Fig. C.7 Fortification No. 2, before Shot 9

Fig. C.8 Fortification No. 2, after Shot 9

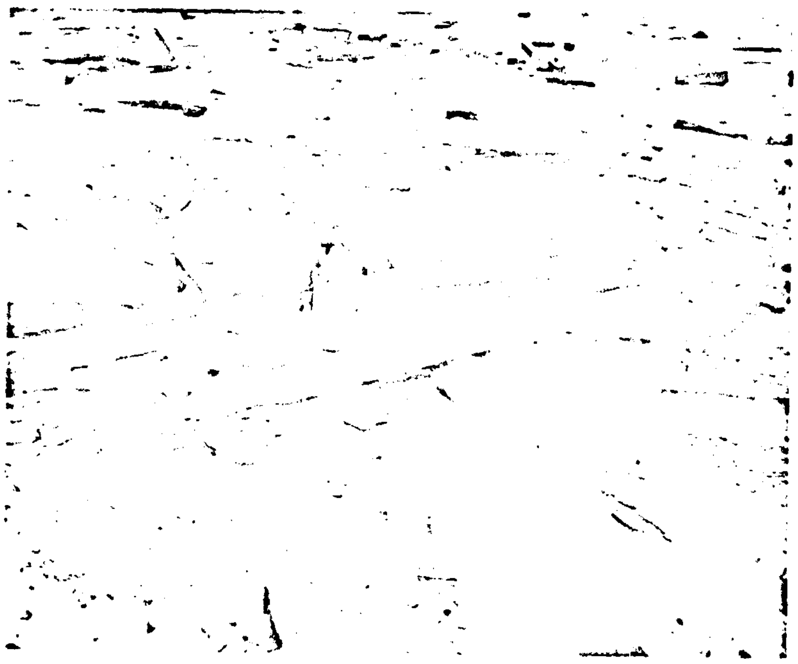


Fig. C.9 Fortification No.2, after Shot 10

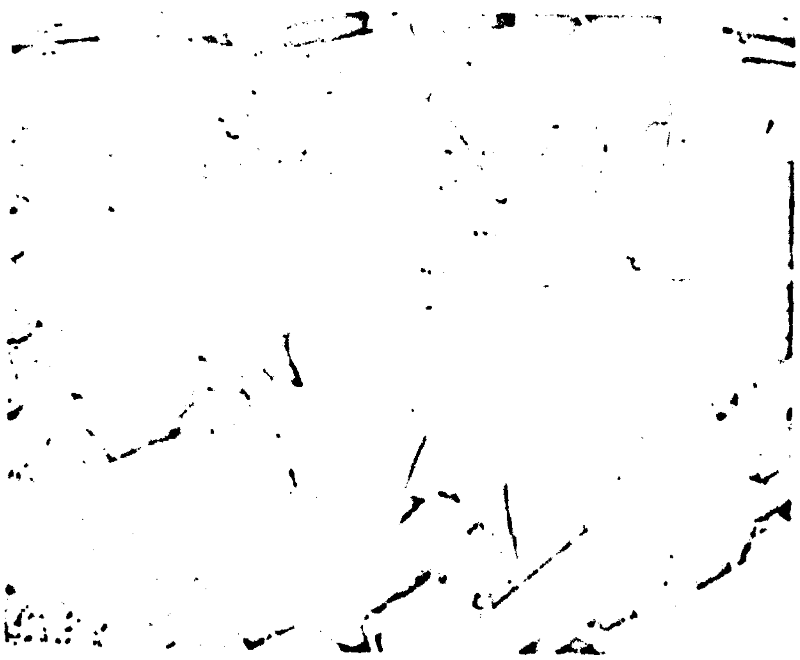


Fig. C.10 Fortification No. 2, after Shot 10

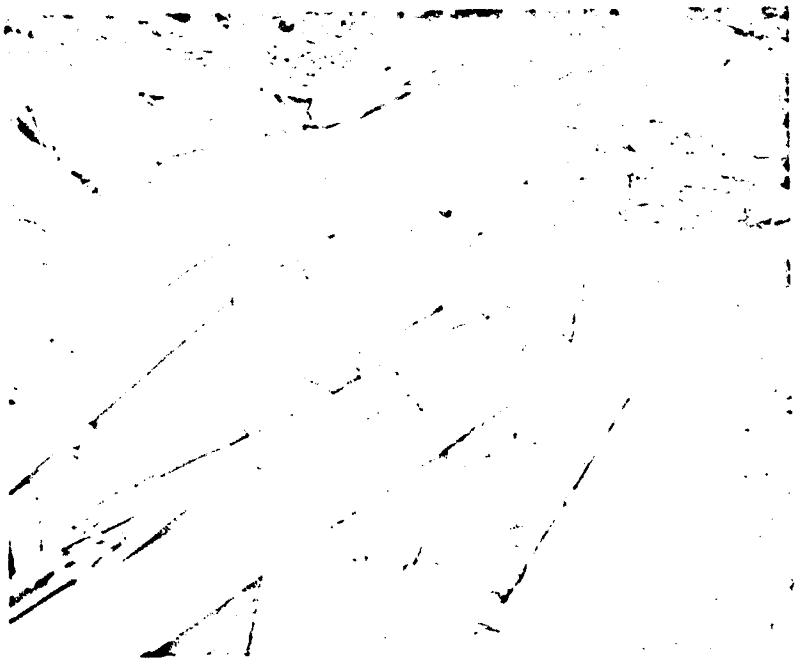


Fig. C.11 Fortification No. 2, after Shot 10

Fig. C.12 Fortification No. 3, before Shot 9

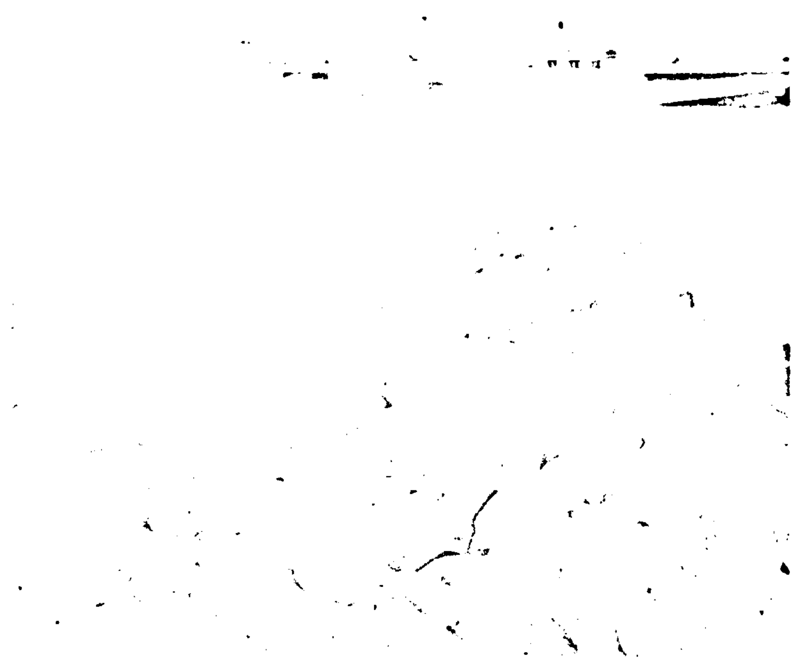


Fig. C.13 Fortification No. 3, after Shot 9

Fig. C.14 Fortification No. 3, after Shot 10

Fig. C.15 Fortification No. 3, after Shot 10

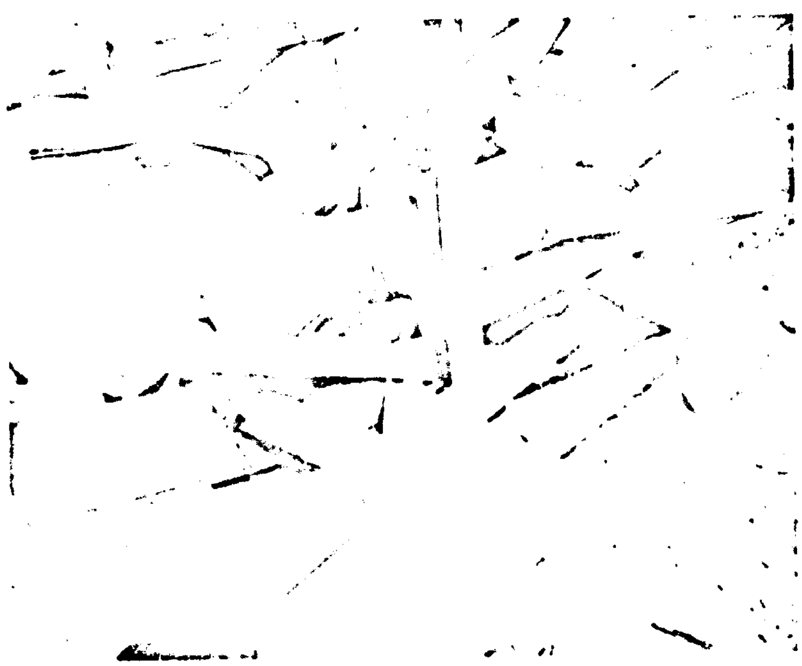


Fig. C.16 Fortification No. 3, after Shot 10

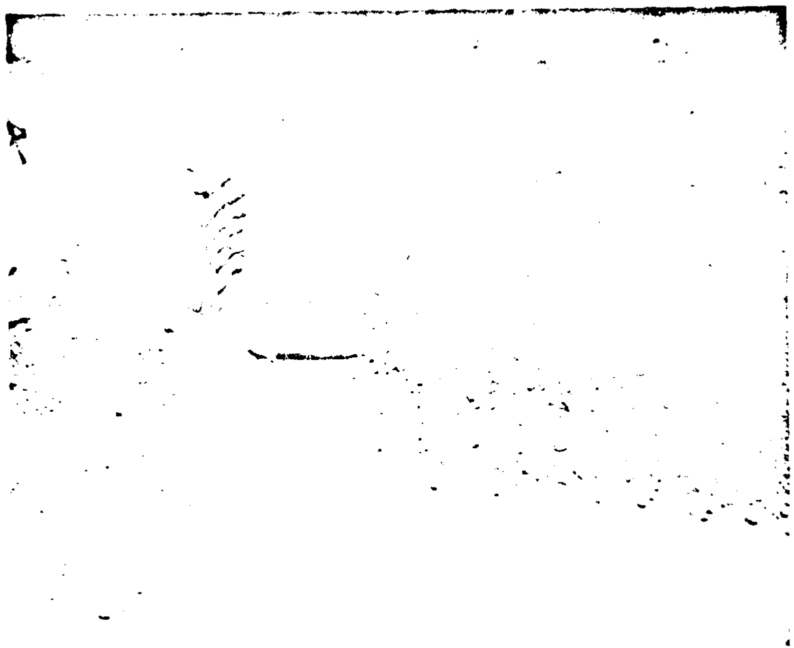


Fig. C.17 Fortification No. 4, before Shot 9

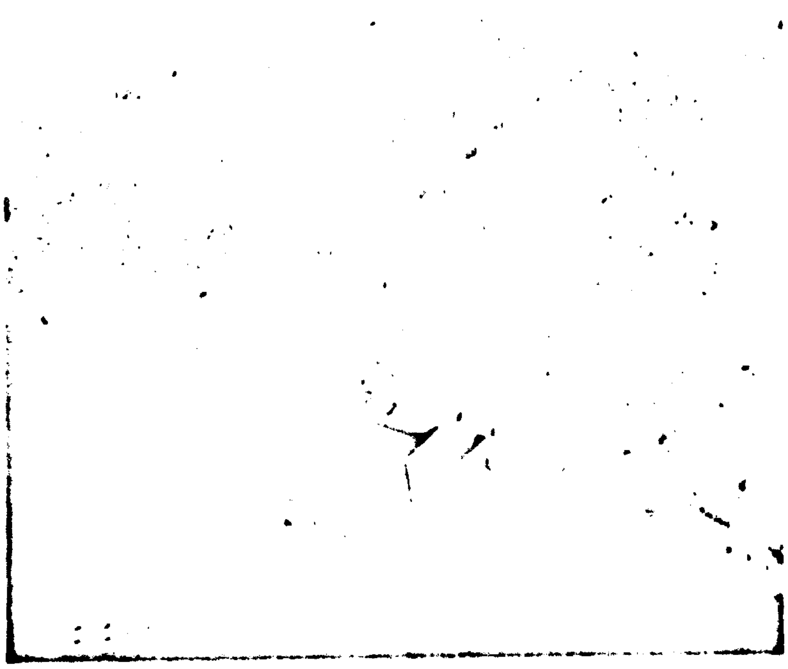


Fig. C.18 Fortification No. 4, after Shot 9

Fig. C.19 Fortification No. 4, after Shot 9

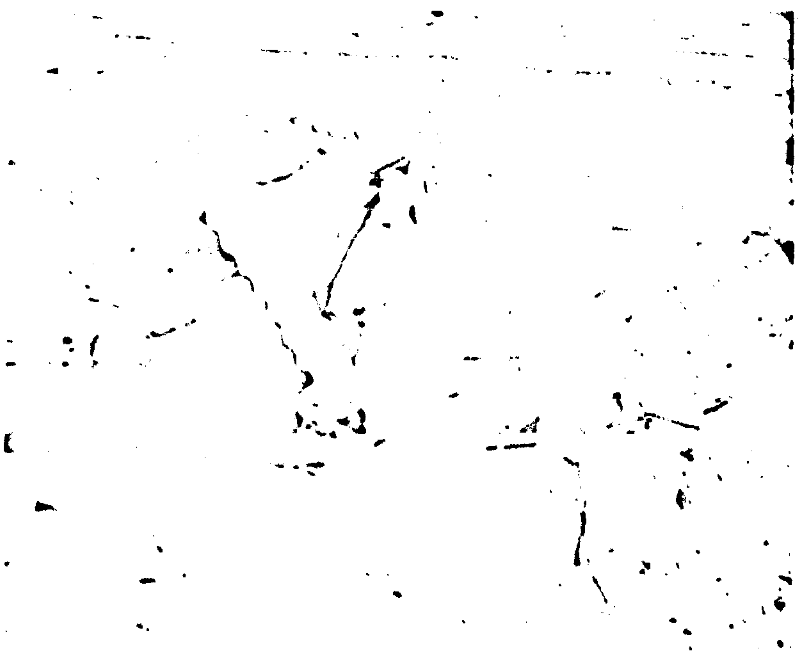


Fig. C.20 Fortification No. 4, after Shot 10

Fig. C.21 Fortification No. 5, before Shot 9

Fig. C.22 Fortification No. 5, after Shot 9

Fig. C.23 Fortification No. 5, after Shot 10

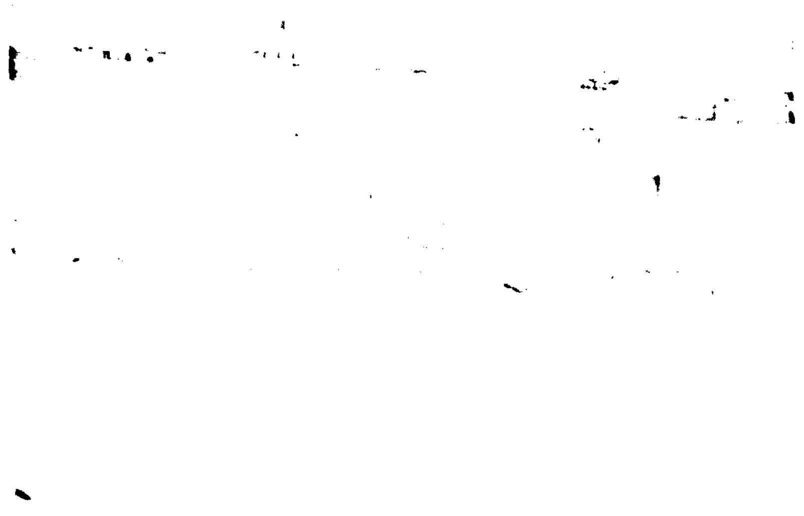


Fig. C.24 Fortification No. 6, before Shot 9

Fig. C.25 Fortification No. 6, before Shot 9

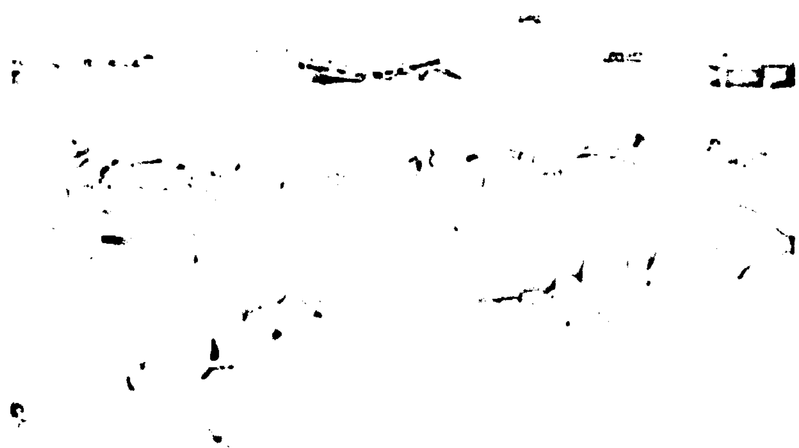


Fig. C. 26 Fortification No. 6, after Shot 9

Fig. C.27 Fortification No. 6, after Shot 9

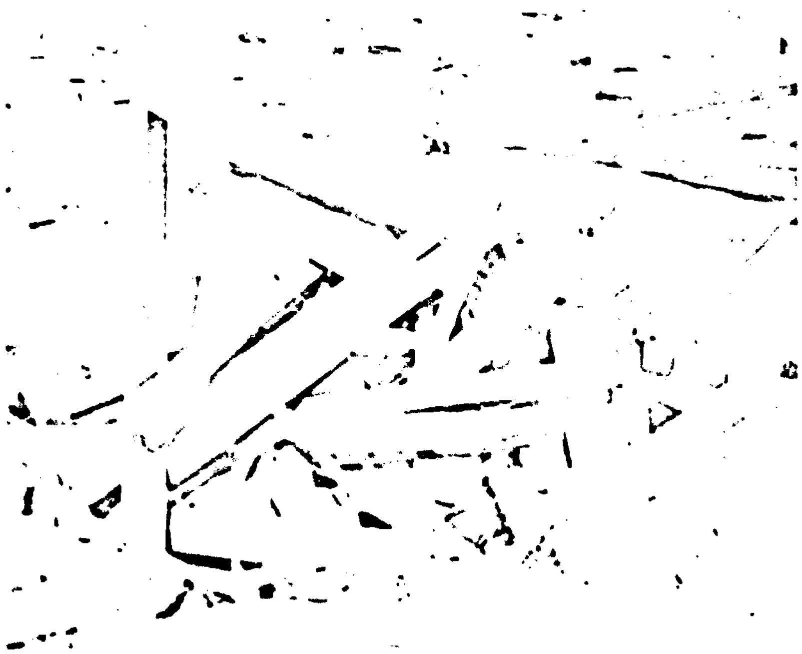


Fig. C.28 Fortification No. 6, after Shot 10

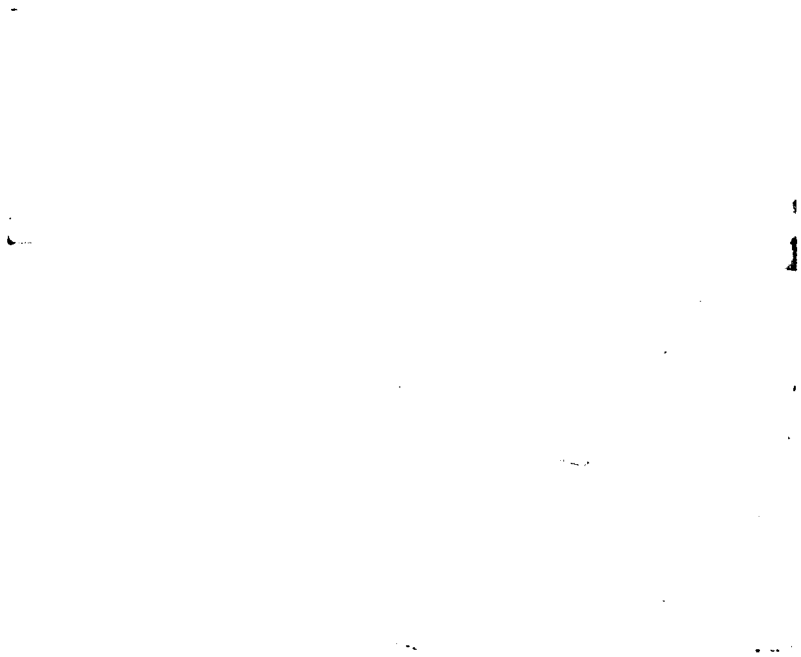


Fig. C.29 Fortification No. 7, before Shot 9

Fig. C.30 Fortification No. 7, before Shot 9

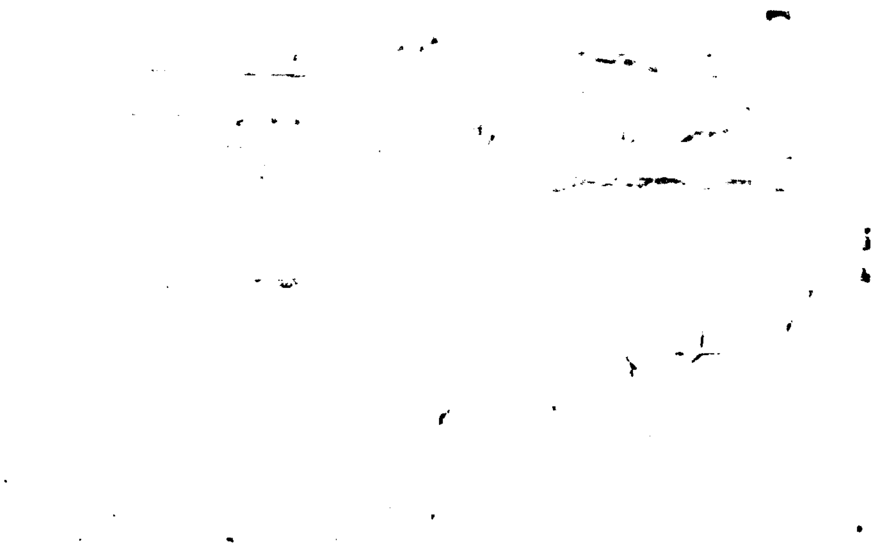


Fig. C.31 Fortification No. 7, after Shot 9

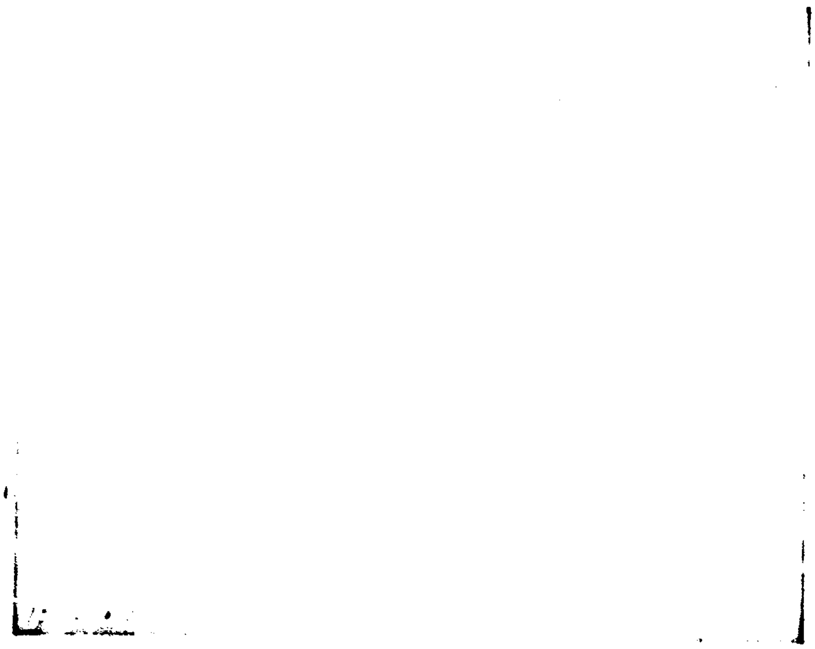


Fig. C.32 Fortification No. 7, after Shot 9

Fig. C.33 Fortification No. 7, after Shot 10

Fig. C.34 Fortification No. 8, before Shot 9

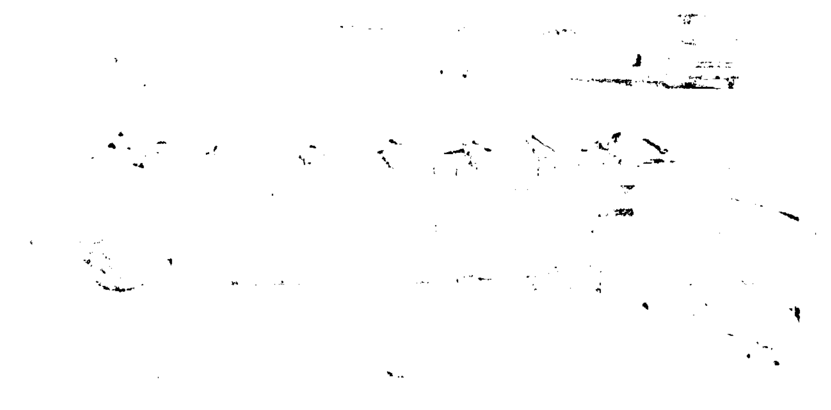


Fig. C.35 Fortification No. 8, after Shot 9

Fig. C.36 Fortification No. 8, after Shot 9

Fig. C.37 Fortification No. 8, after Shot 10

Fig. C.38 Fortification No. 9, before Shot 9

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Fig. C.39 Fortification No. 9, before Shot 9

Fig. C.40 Fortification No. 9, after Shot 9

Fig. C.41 Fortification No. 9, after Shot 9

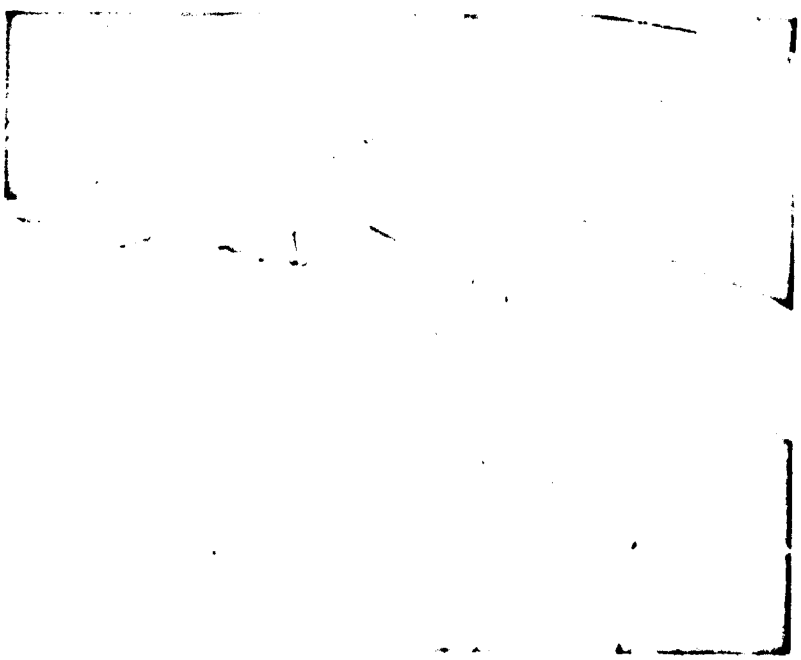

Fig. C.42 Fortification No. 9, after Shot 9

Fig. C.43 Fortification No. 9, after Shot 10

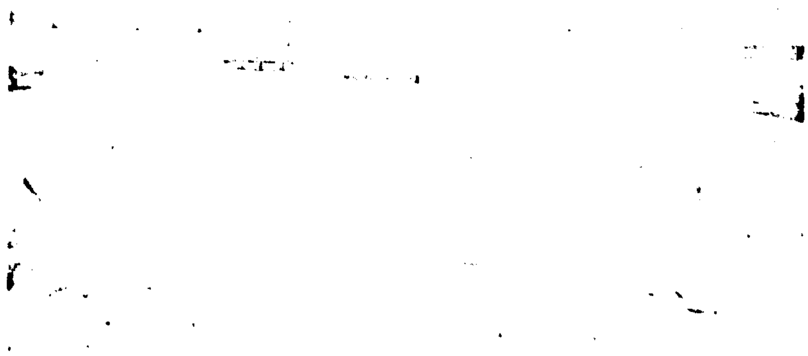

Fig. C.44 Fortification No. 10, before Shot 9

Fig. C.45 Fortification No. 10, before Shot 9

Fig. C.46 Fortification No. 10, after Shot 9

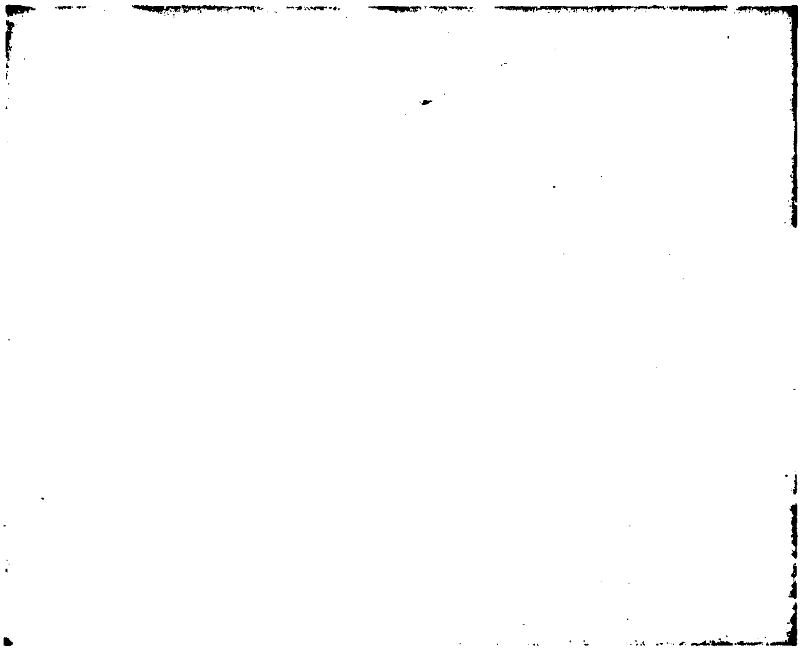

Fig. C.47 Fortification No. 10, after Shot 9

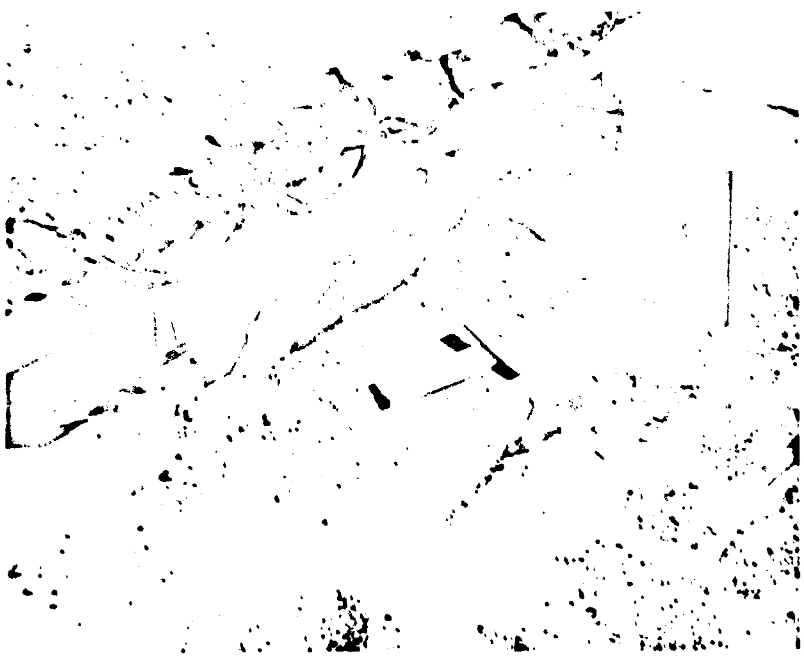

Fig. C.48 Fortification No. 10, after Shot 9

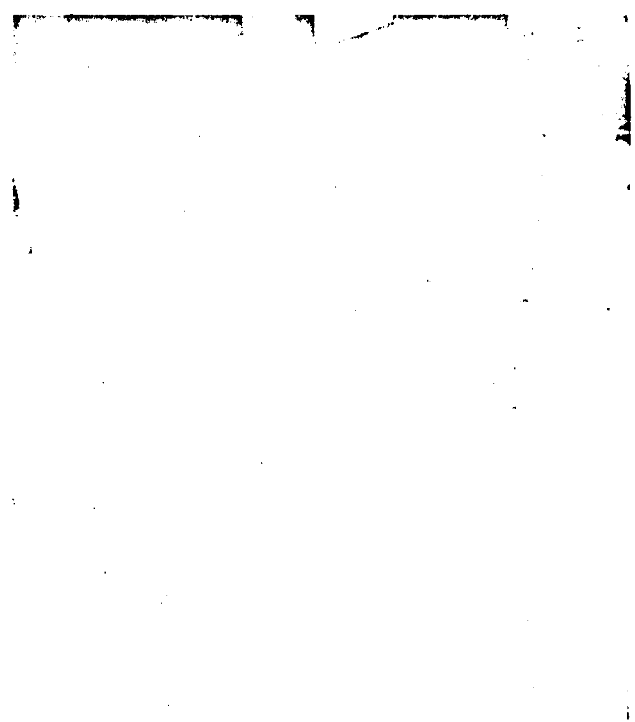

Fig. C.49 Fortification No. 10, after Shot 9

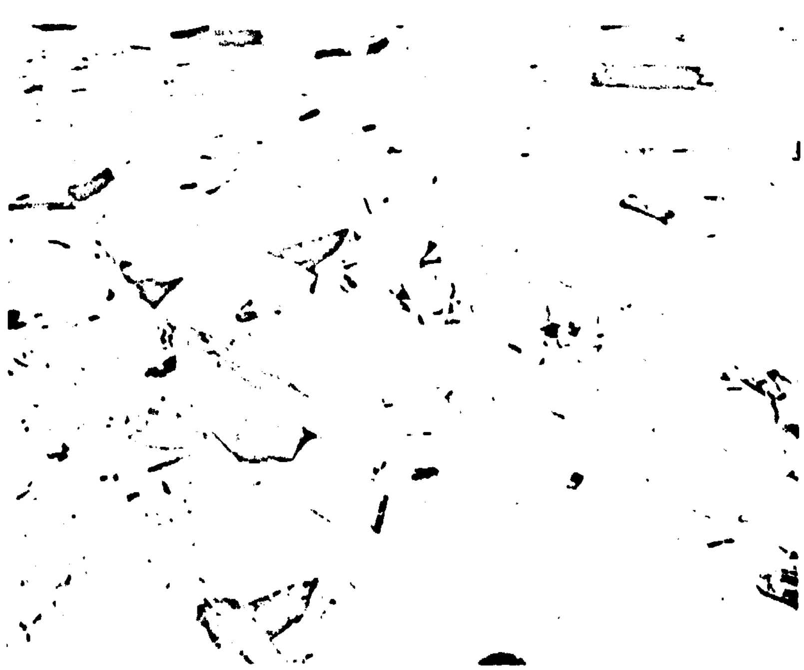

Fig. C.50 Fortification No. 10, after Shot 10

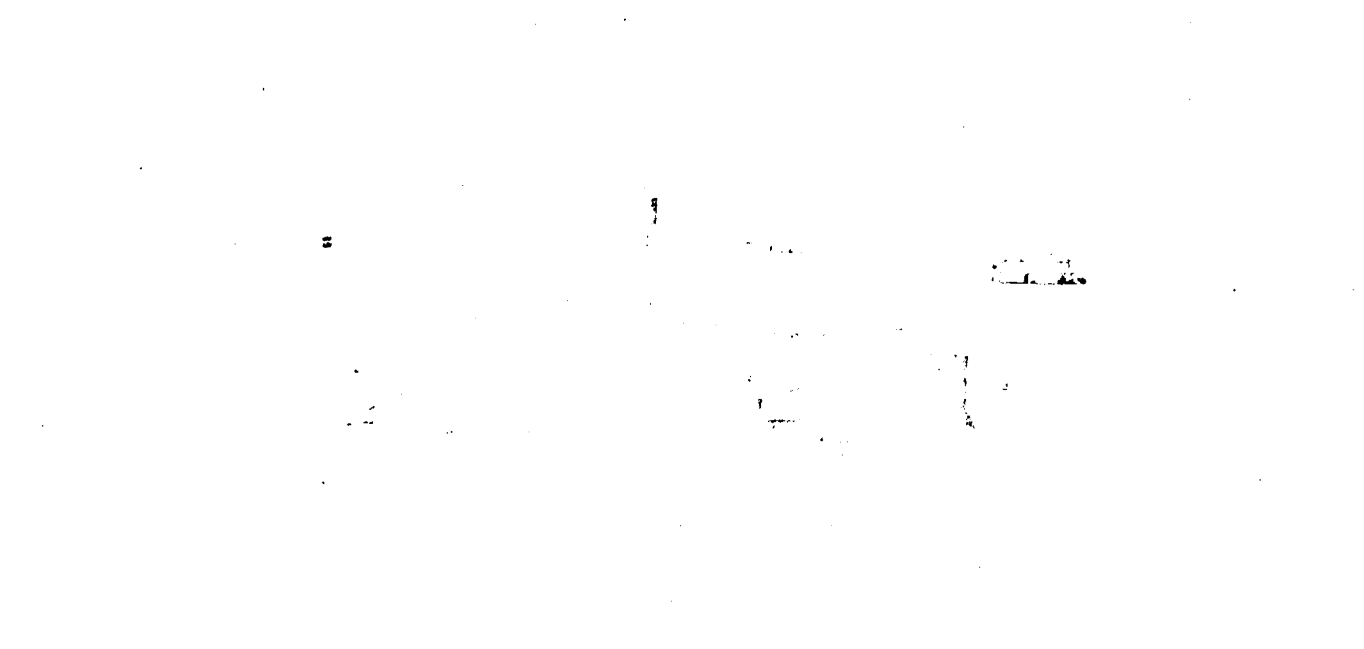

Fig. C.51 Fortification No. 11, before Shot 9

Fig. C.52 Fortification No. 11, after Shot 9

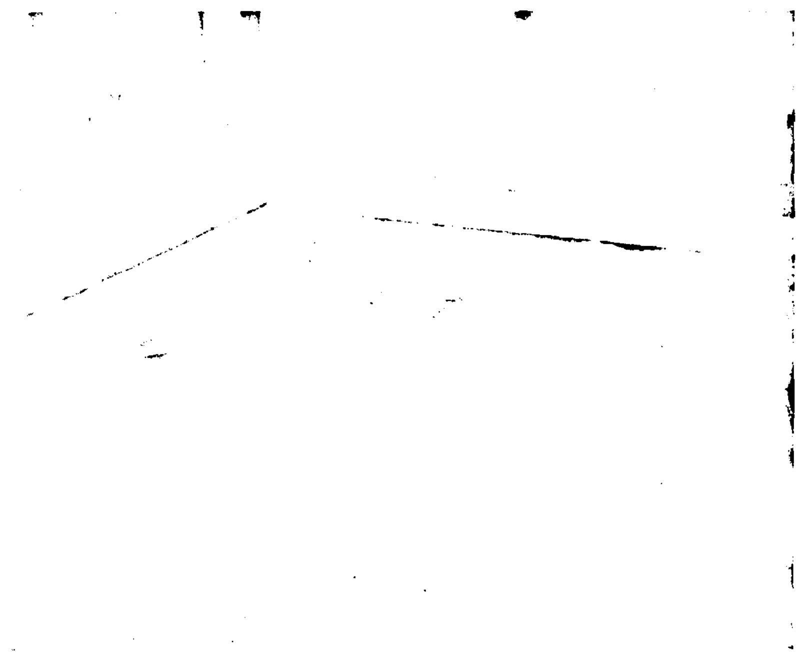

Fig. C.53 Fortification No. 11, after Shot 9

Fig. C.54 Fortification No. 11, after Shot 10

Fig. C.55 Fortification No. 12, before Shot 9

Fig. C.56 Fortification No. 12, before Shot 9

Fig. C.57 Fortification No. 12, after Shot 9

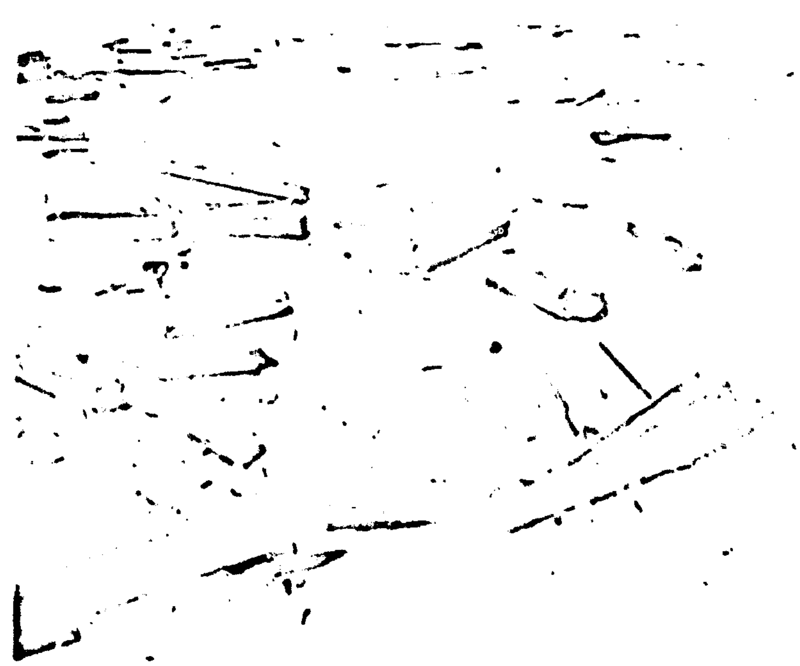

Fig. C.58 Fortification No. 12, after Shot 10

Fig. C.59 Fortification No. 13, before Shot 9

Fig. C.60 Fortification No. 13, before Shot 9

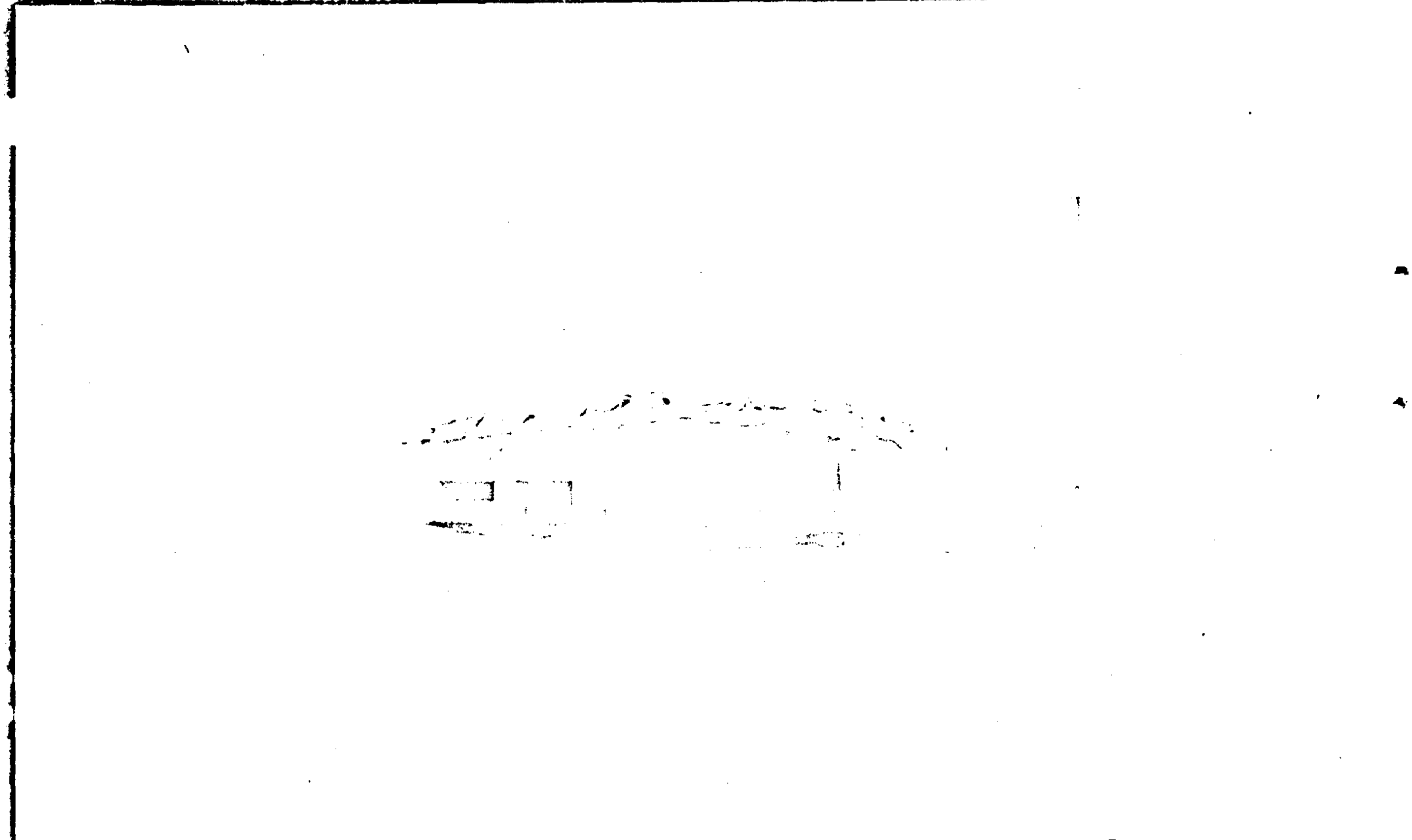

Fig. C.61 Fortification No. 13, after Shot 9

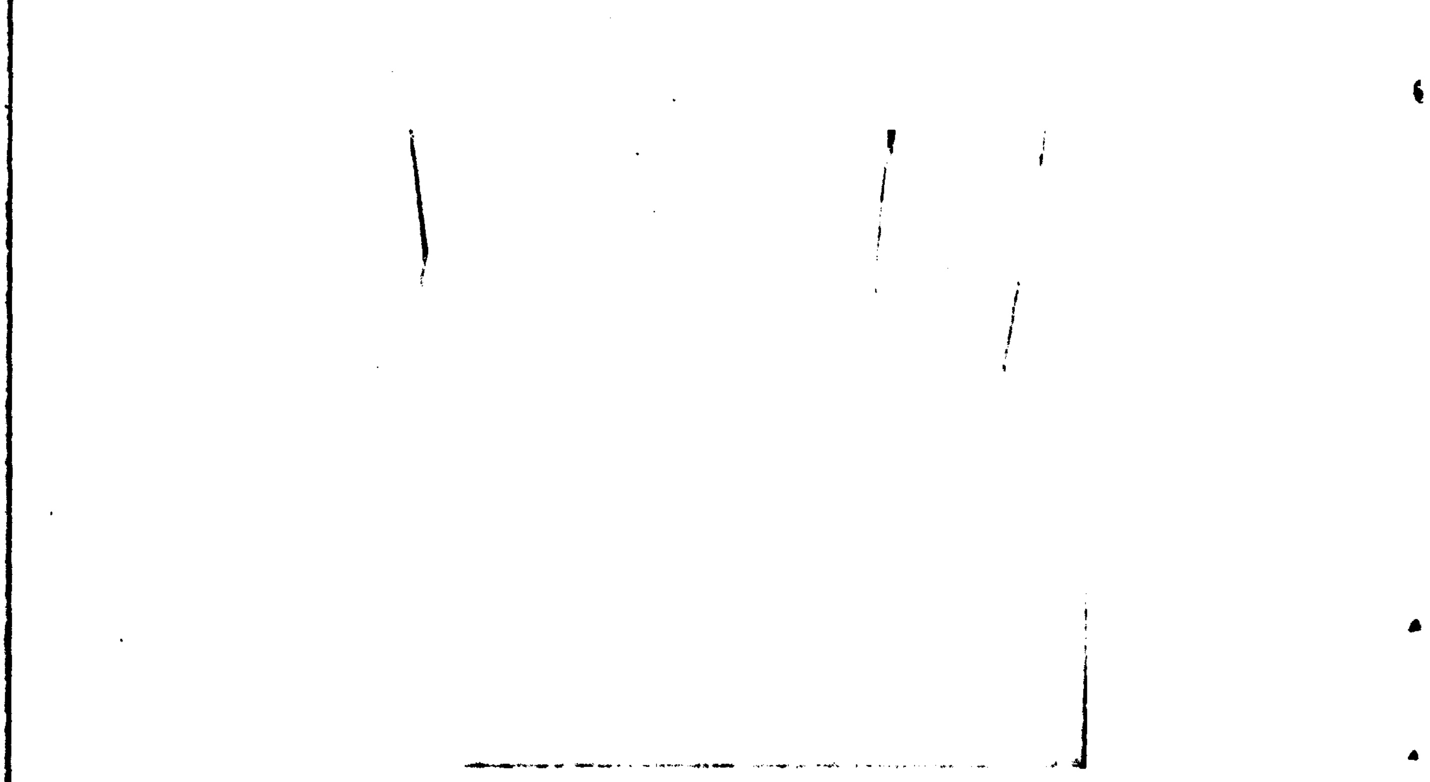

Fig. C.62 Fortification No. 13, after Shot 9

Fig. C.63 Fortification No. 13, after Shot 10

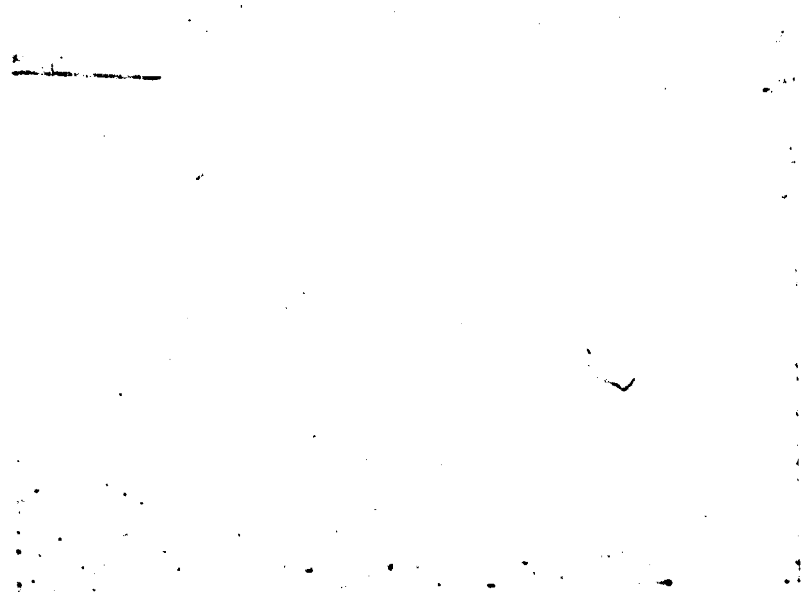

Fig. C.64 Fortification No. 14, before Shot 9

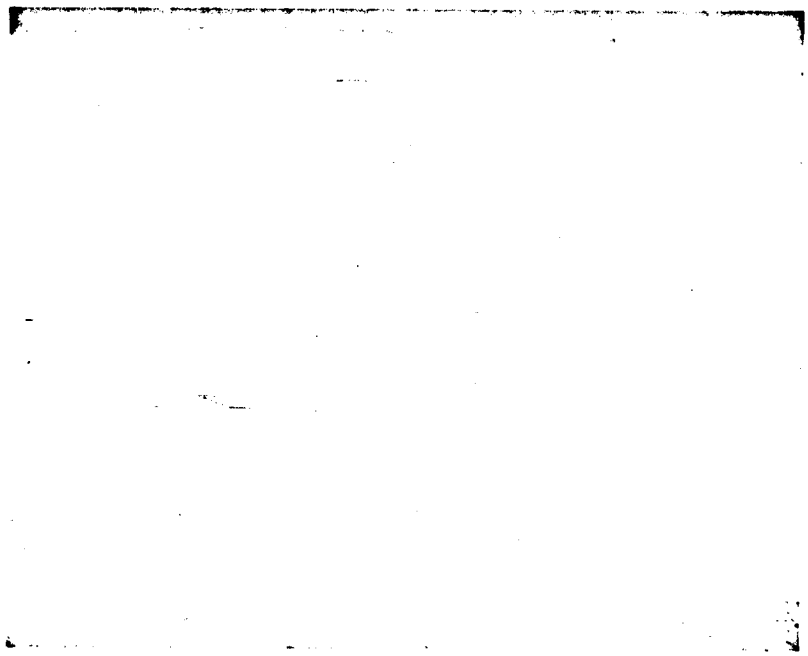

Fig. C.65 Fortification No. 14, before Shot 9

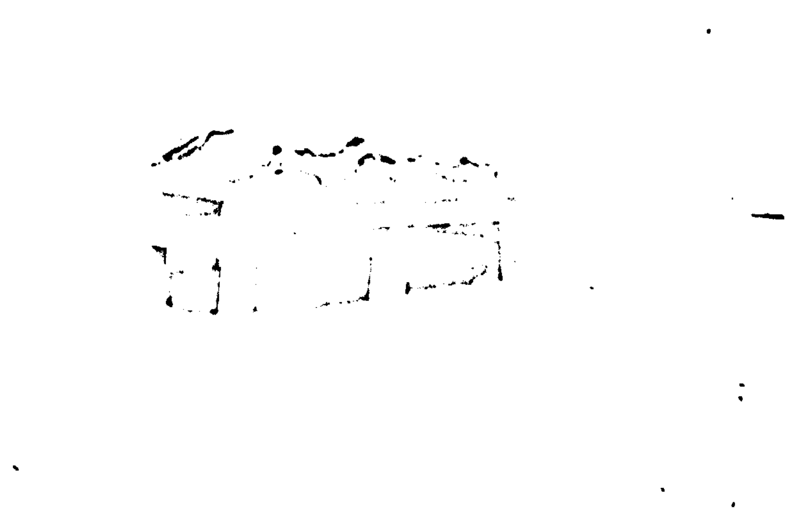

Fig. C.66 Fortification No. 14, after Shot 9

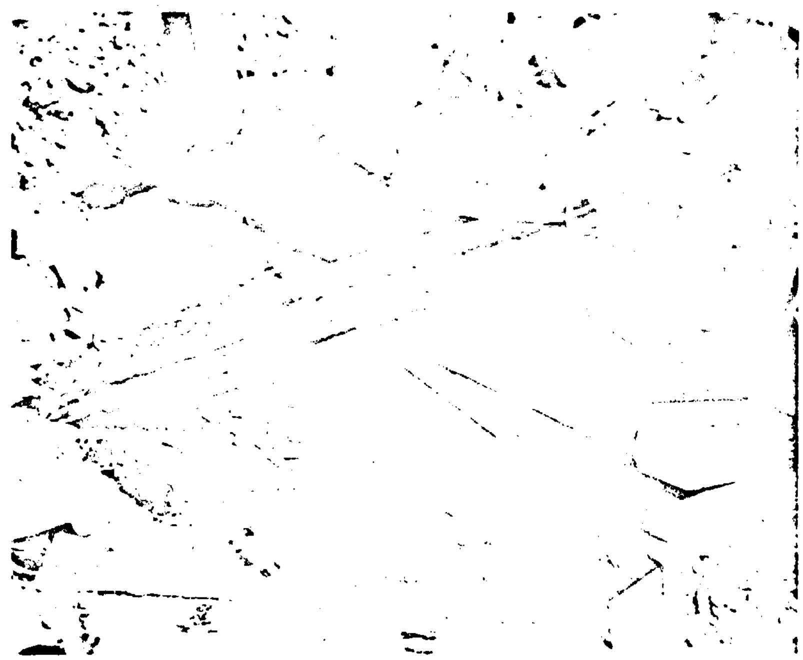

Fig. C.67 Fortification No. 14, after Shot 10

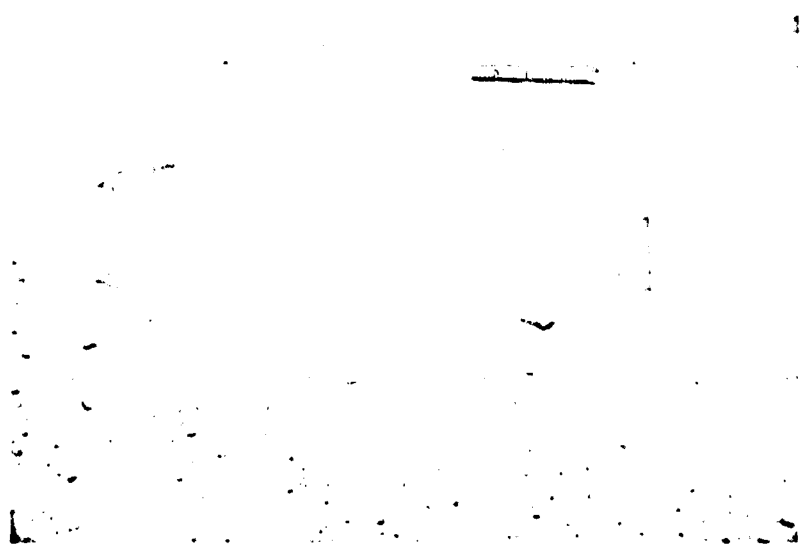

Fig. C.68 Fortification No. 15, before Shot 9

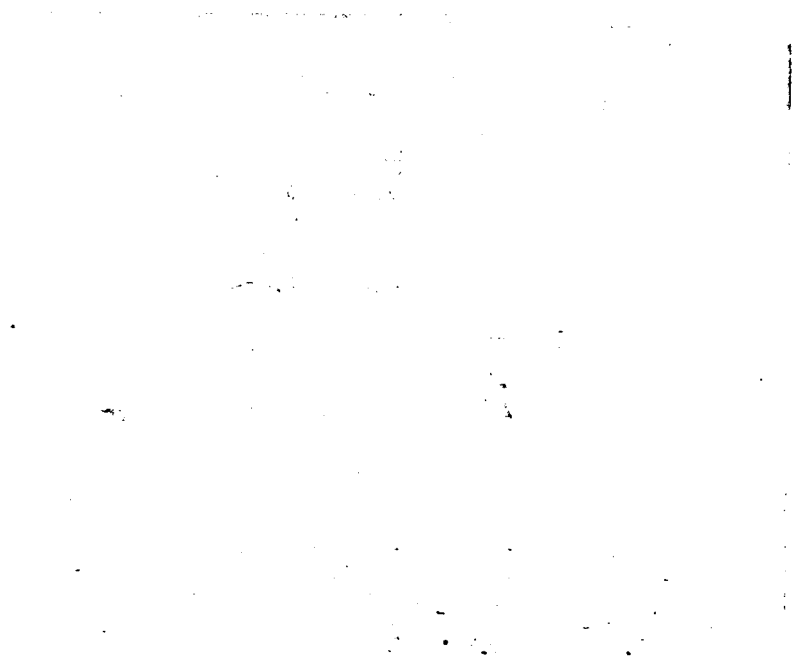

Fig. C.69 Fortification No. 15, before Shot 9

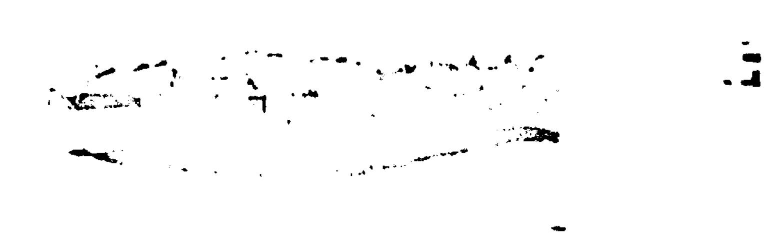

Fig. C.70 Fortification No. 15, after Shot 9

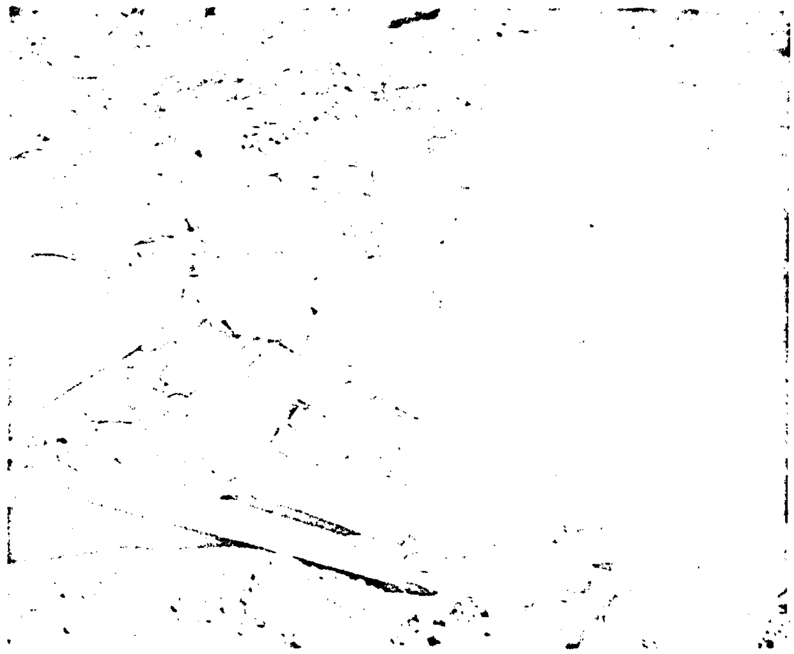

Fig. C.71 Fortification No. 15, after Shot 10

Fig. C.72 Fortification No. 16, before Shot 9

Fig. C.73 Fortification No. 16, after Shot 9

Fig. C.74 Fortification No. 16, after Shot 10

Fig. C.75 Fortification No. 17, before Shot 9

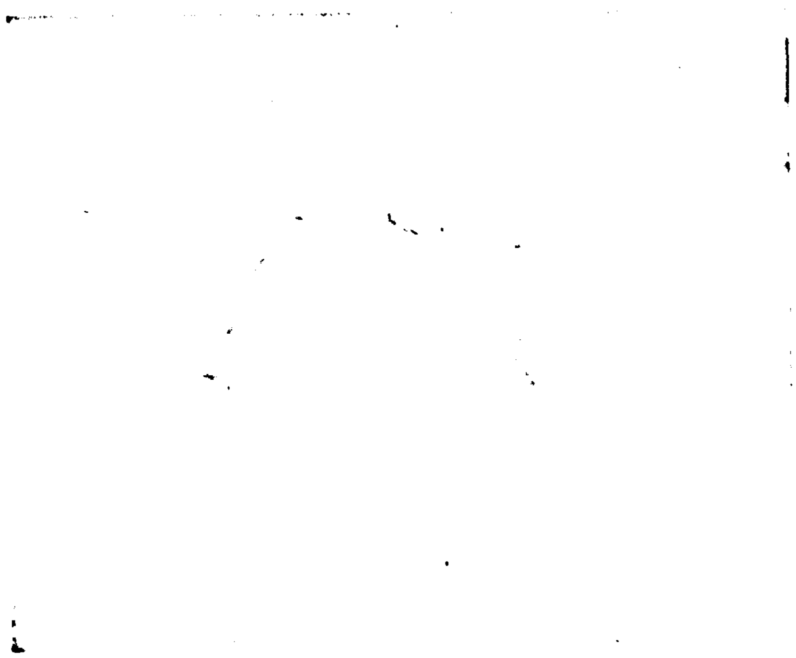

Fig. C.76 Fortification No. 17, before Shot 9

Fig. C.77 Fortification No. 17, after Shot 9

Fig. C.78 Fortification No. 17, after Shot 10

Fig. C.79 Fortification No. 18, before Shot 9

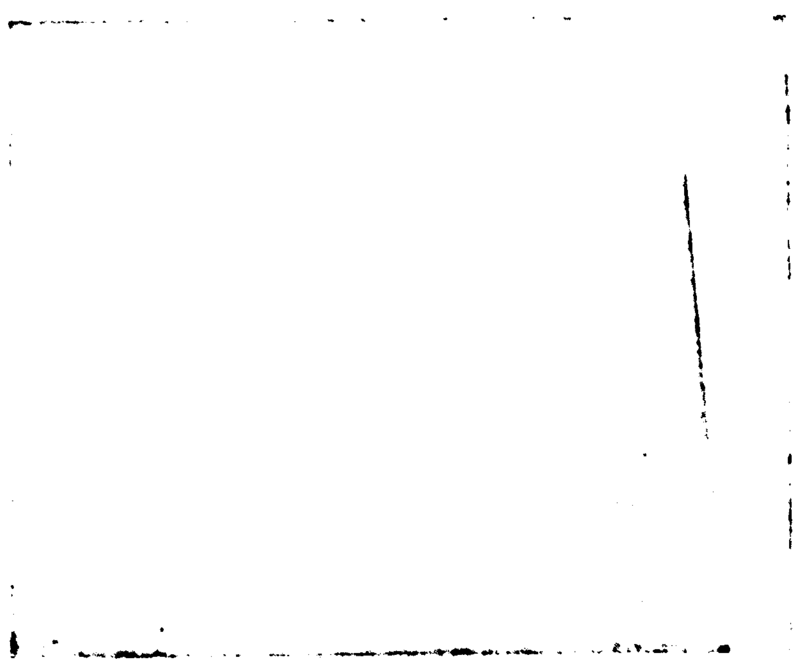

Fig. C.80 Fortification No. 18, before Shot 9

Fig. C.81 Fortification No. 18, after Shot 9

Fig. C.82 Fortification No. 18, after Shot 9

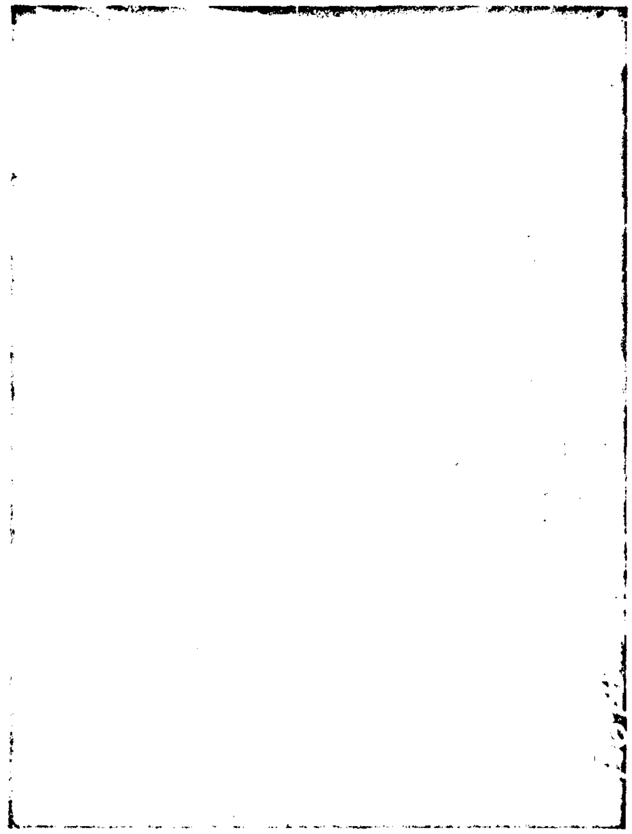

Fig. C.83 Fortification No. 18, after Shot 9

Fig. C.84 Fortification No. 19, before Shot 9

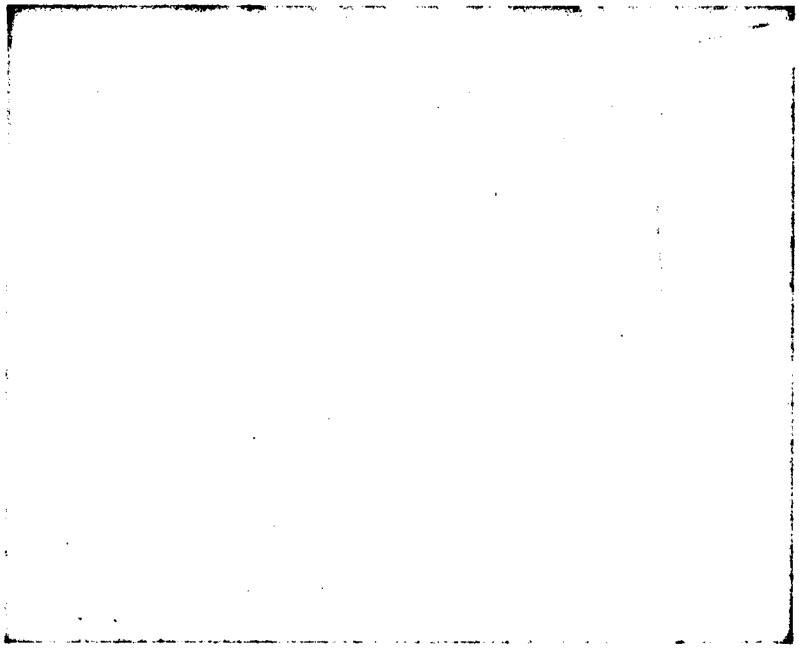

Fig. C.85 Fortification No. 19, before Shot 9

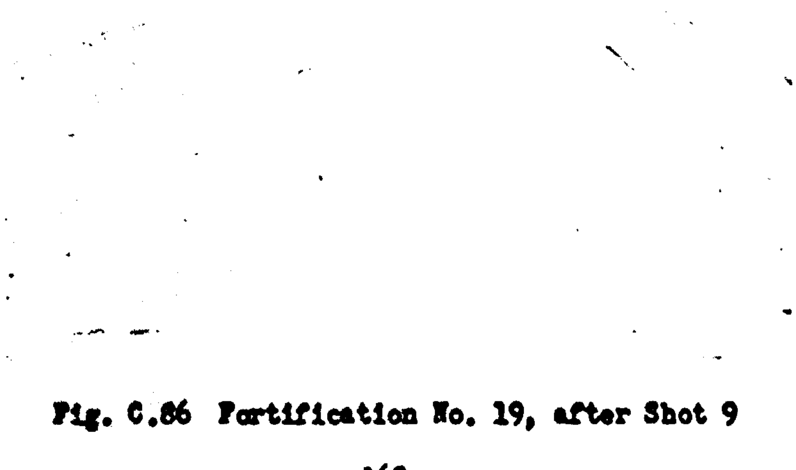

Fig. C.86 Fortification No. 19, after Shot 9

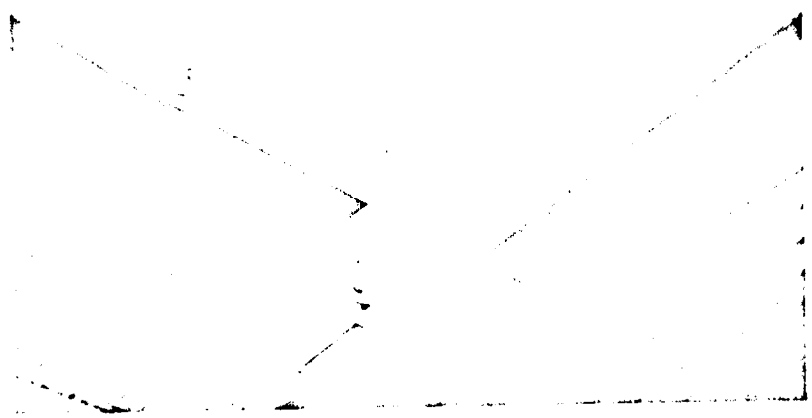

Fig. C.87 Fortification No. 19, after Shot 9

Fig. C.88 Fortification No. 20, before Shot 9

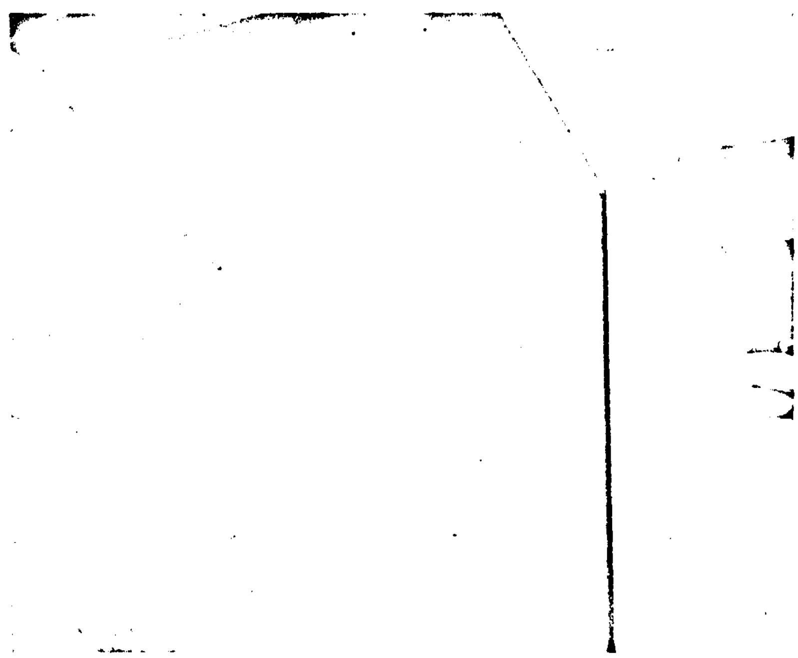

Fig. C.89 Fortification No. 20, before Shot 9

Fig. C.90 Fortification No. 20, after Shot 9

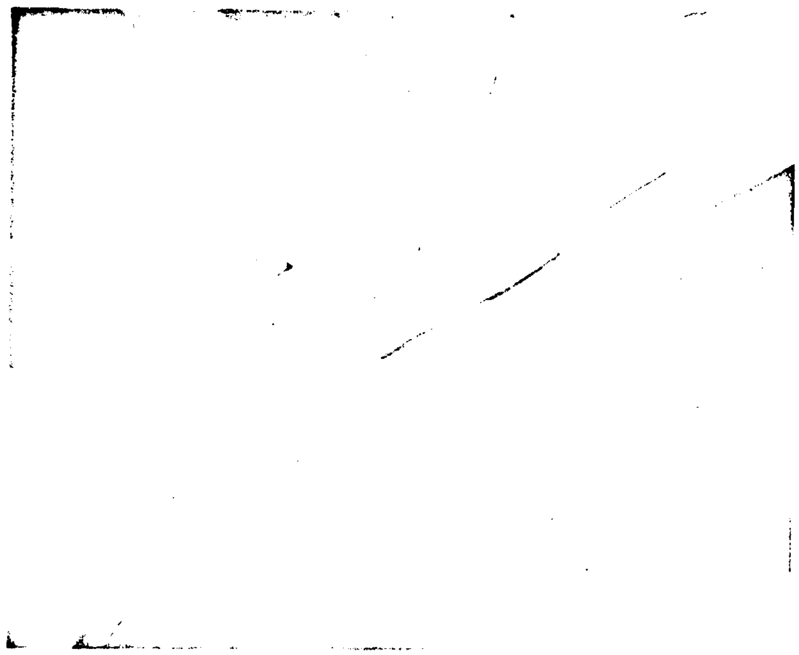

Fig. C.91 Fortification No. 20, after Shot 9

Fig. C.92 Fortification No. 20, after Shot 9

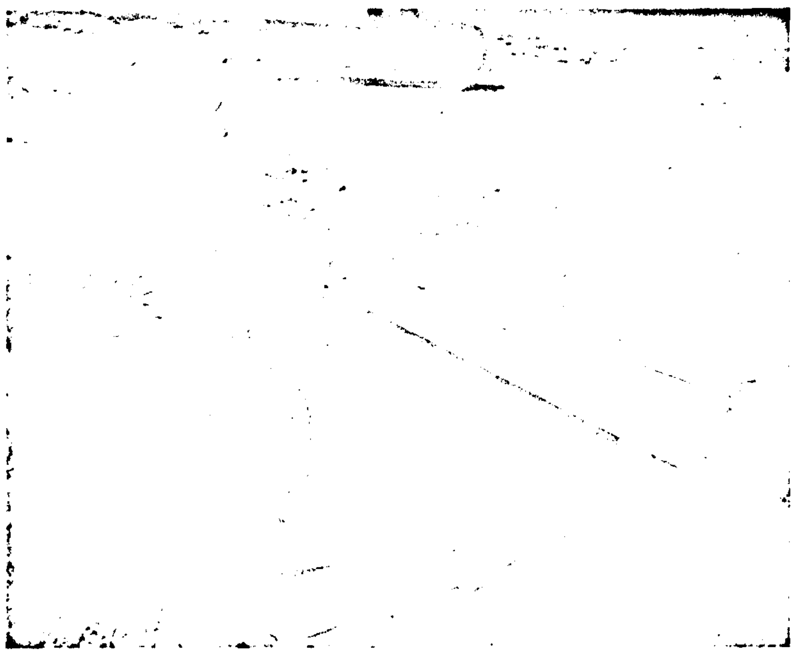

Fig. C.93 Fortification No. 21, under Construction

Fig. C.94 Fortification No. 21, after Shot 9

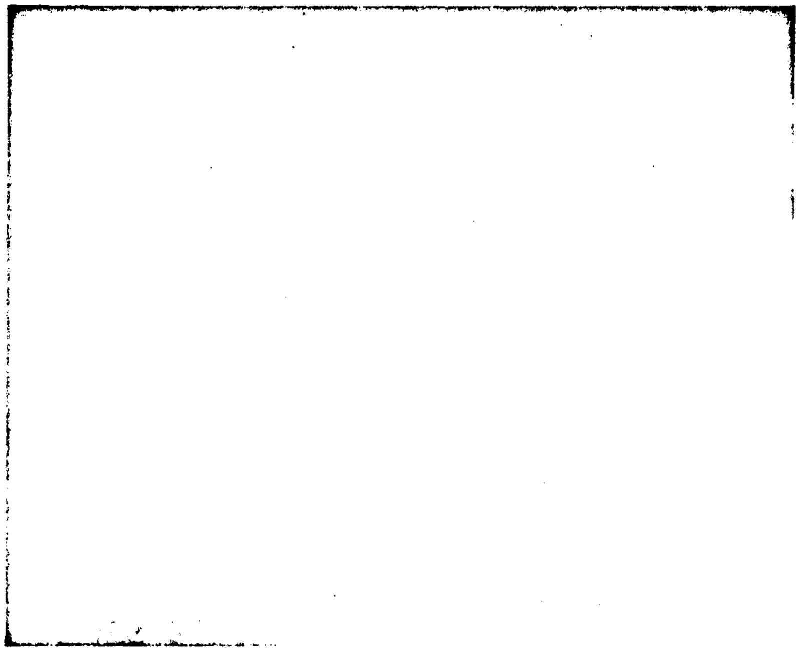

Fig. C.95 Fortification No. 21, after Shot 9

Fig. C.96 Fortification No. 22, before Shot 9

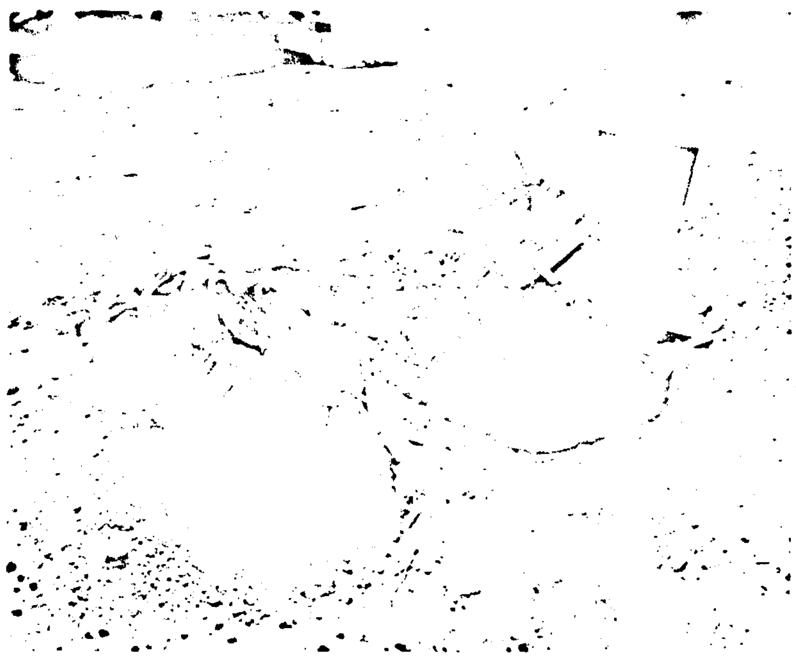

Fig. C.97 Fortification No. 22, after Shot 9

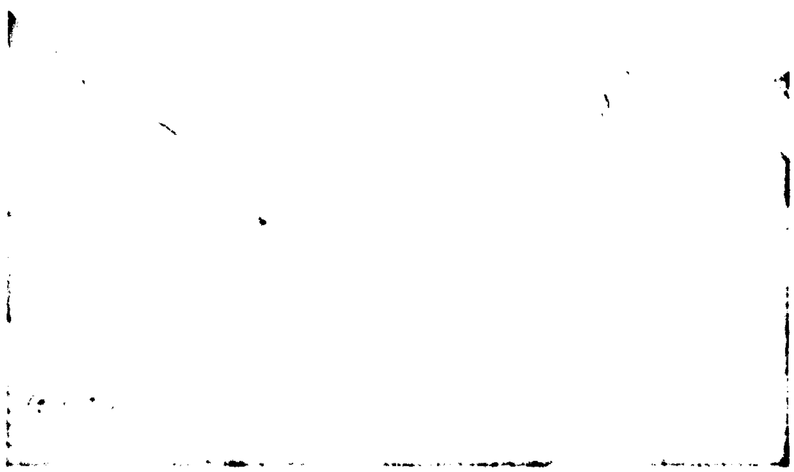

Fig. C.98 Fortification No. 22, after Shot 9

Fig. C.99 Fortification No. 23, before Shot 9

Fig. C.100 Fortification No. 23, before Shot 9

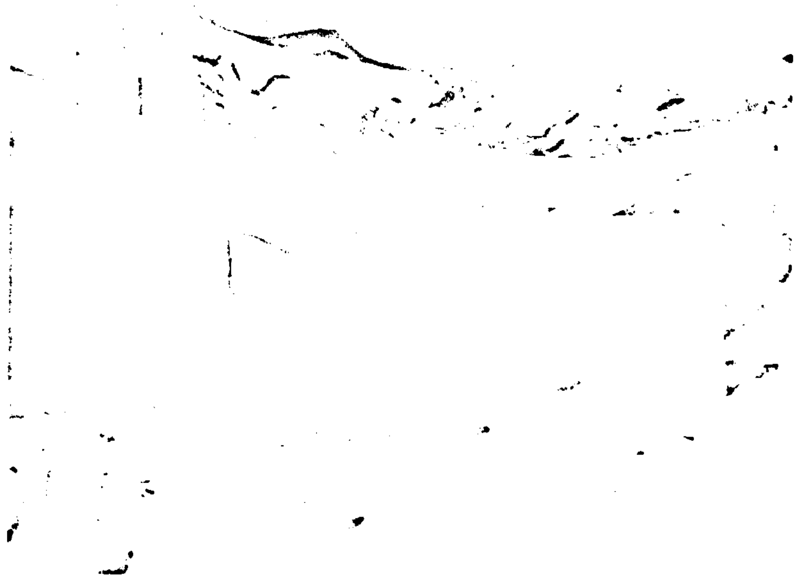

Fig. C.101 Fortification No. 23, after Shot 9

Fig. C.102 Fortification No. 23, after Shot 9

Fig. C.103 Fortification No. 23, after Shot 9

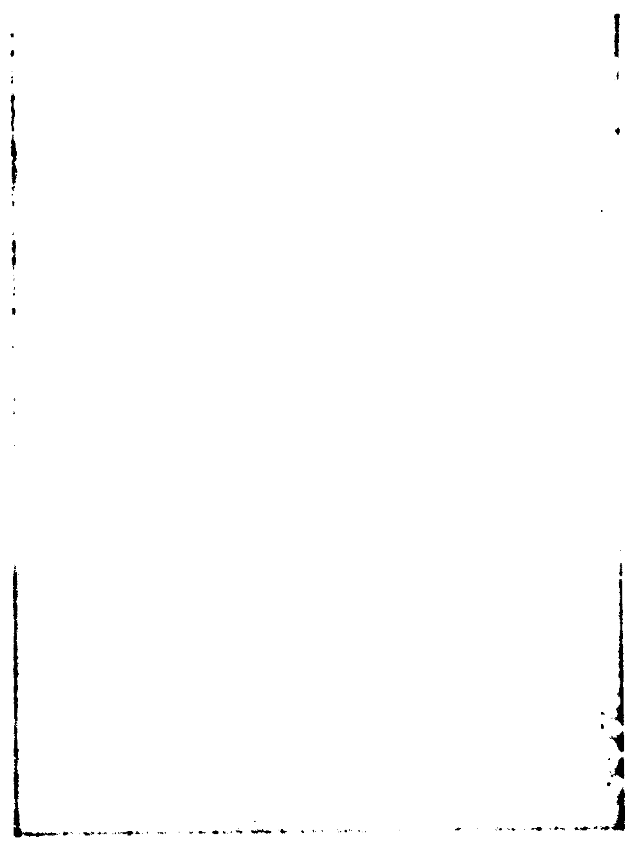

Fig. C.104 Fortification No. 23, after Shot 9

Fig. C.105 Fortification No. 24, before Shot 9

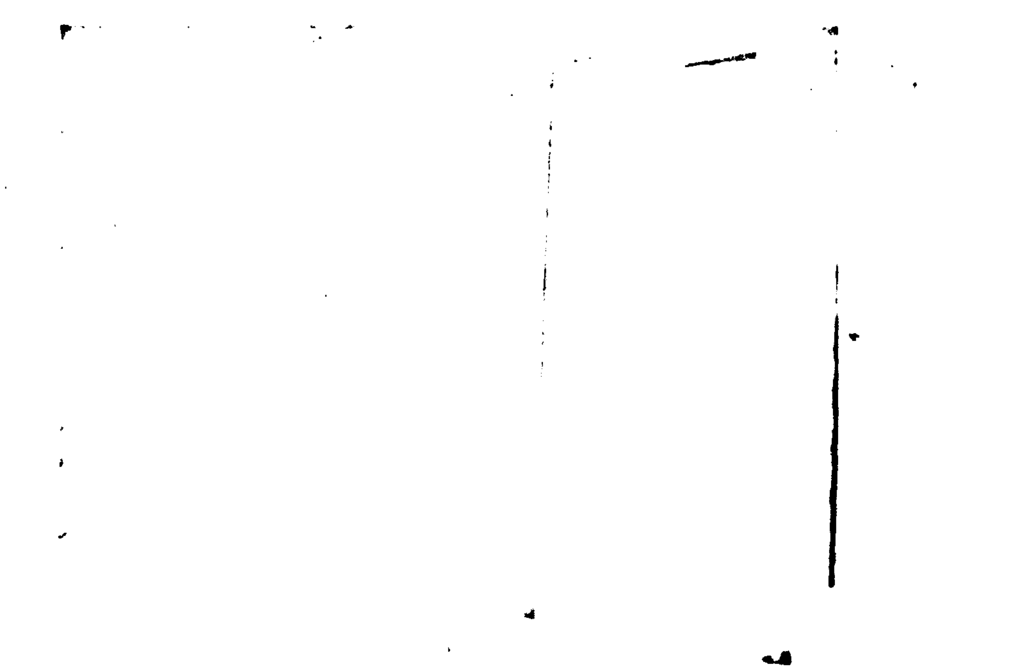

Fig. C.106 Fortification No. 24, before Shot 9

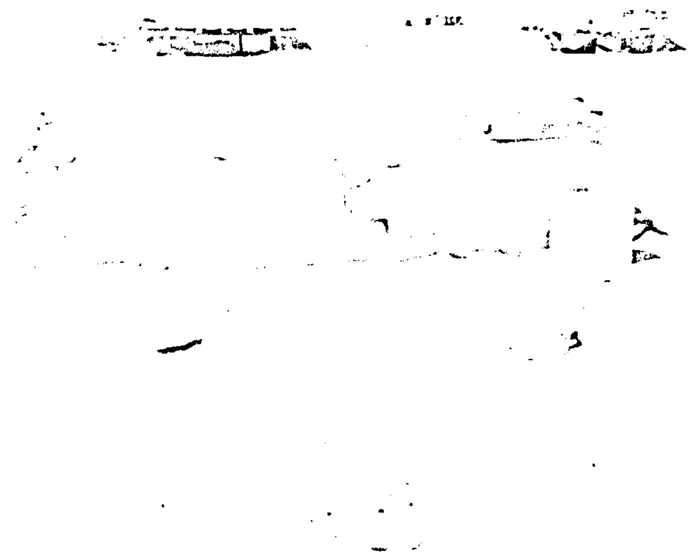

Fig. C.107 Fortification No. 24, after Shot 9

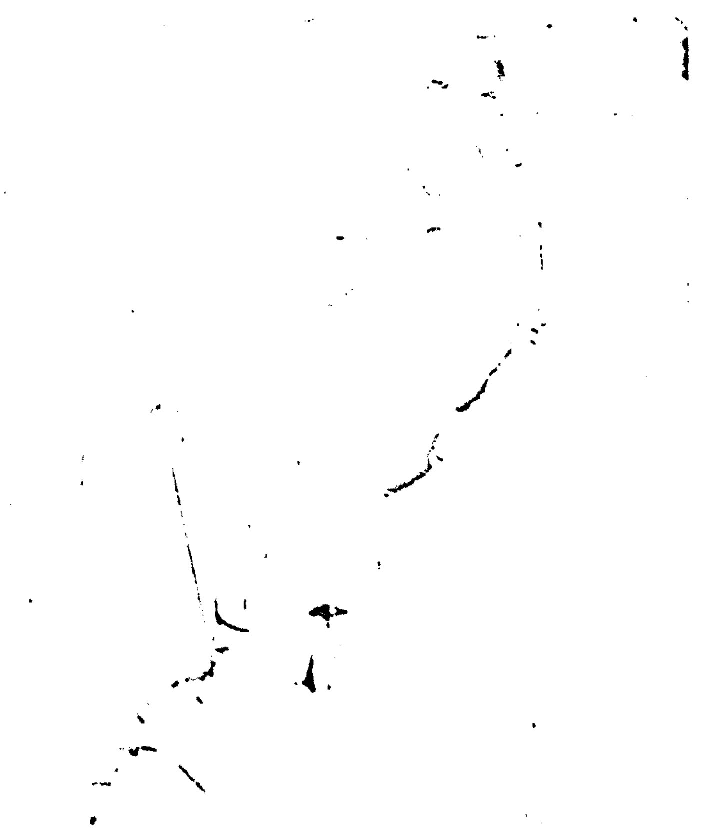

Fig. C.108 Fortification No. 24, after Shot 9

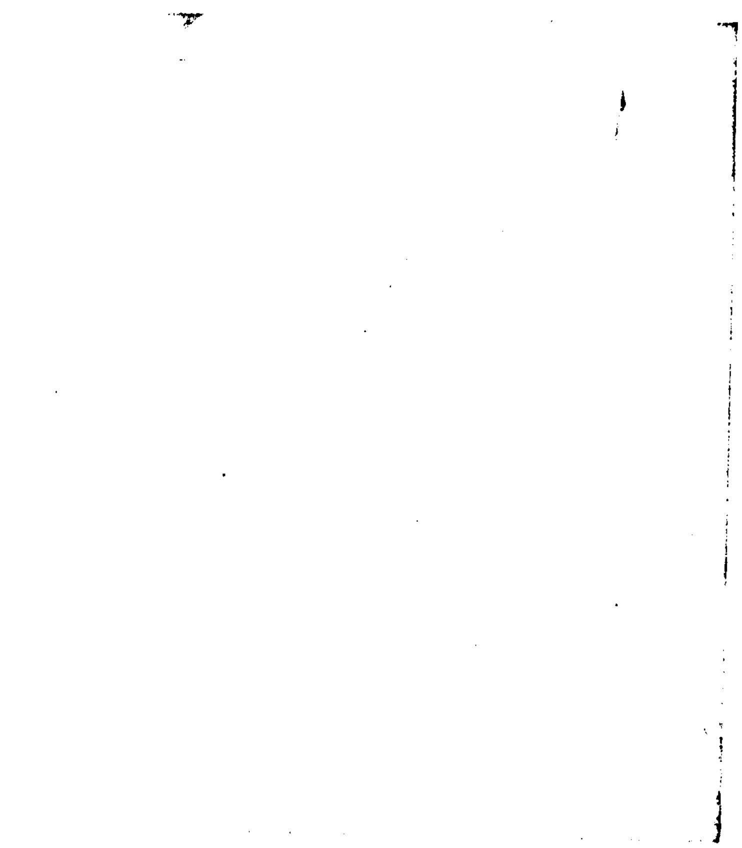

Fig. C.109 Fortification No. 24, after Shot 9

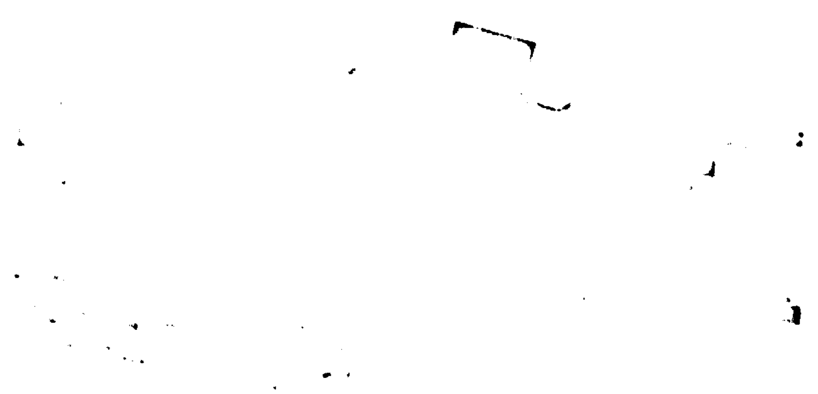

Fig. C.110 Fortification No. 25, before Shot 9

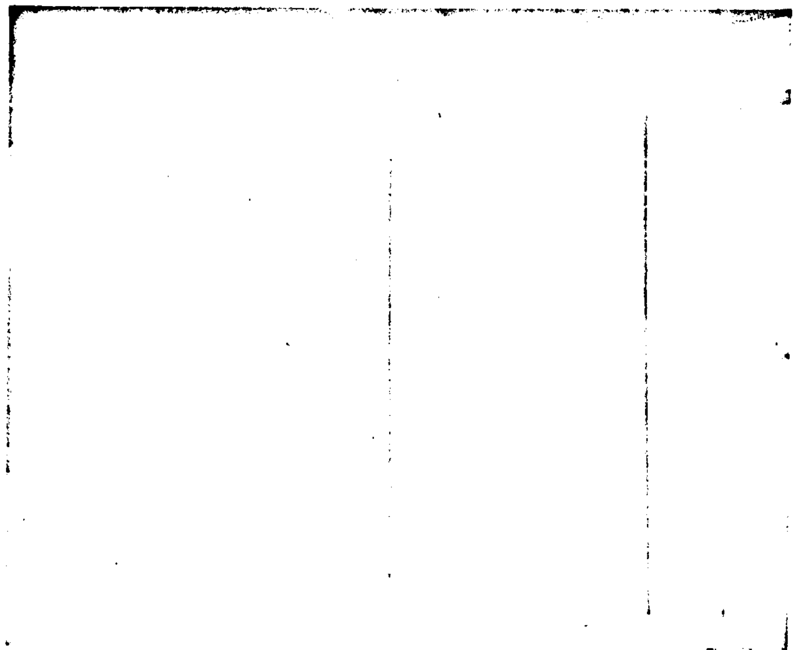

Fig. C.111 Fortification No. 25, before Shot 9

Fig. C.112 Fortification No. 25, after Shot 9

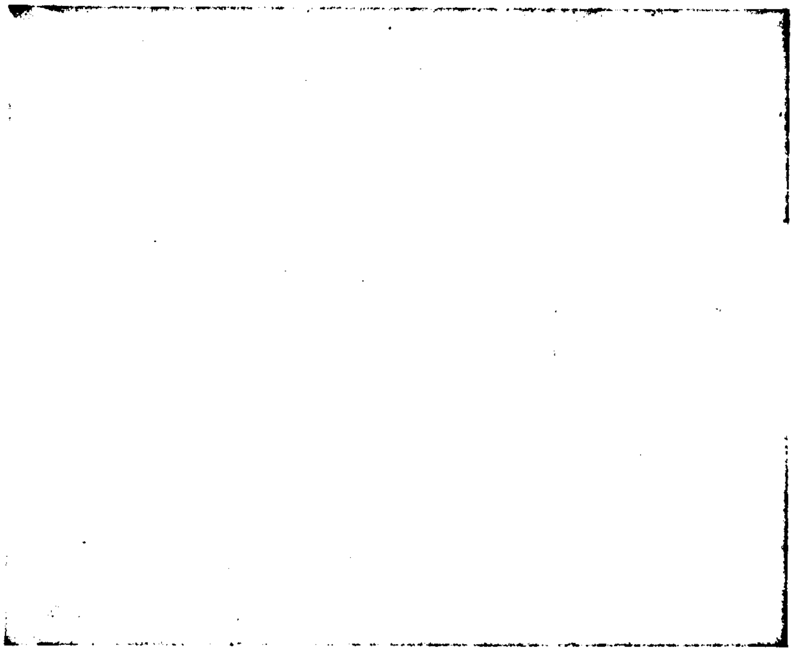

Fig. C.113 Fortification No. 25, after Shot 9

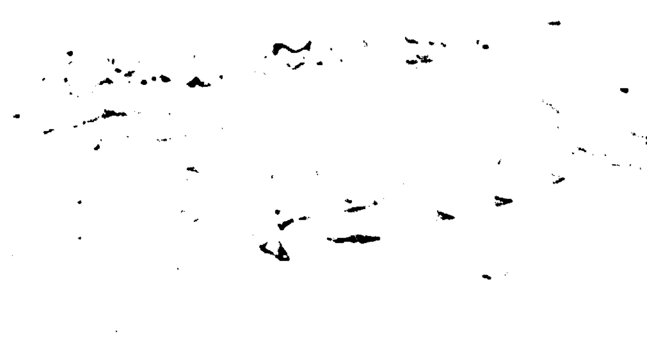

Fig. C.114 Fortification No. 26, after Shot 9

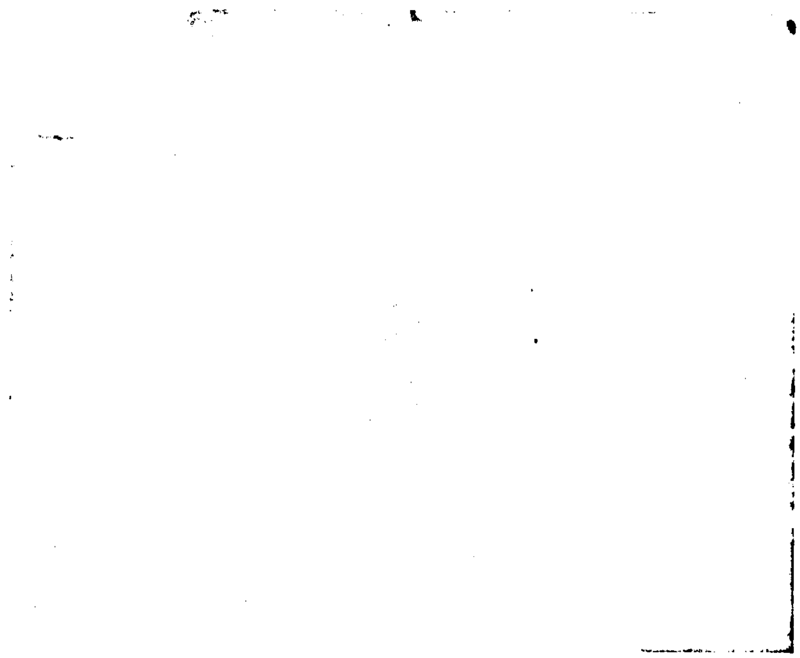

Fig. C.115 Fortification No. 26, after Shot 9

Fig. C.116 Fortification No. 27, after Shot 9

Fig. C.117 Fortification No. 27, after Shot 9

Fig. C.118 Fortification No. 27, after Shot 9

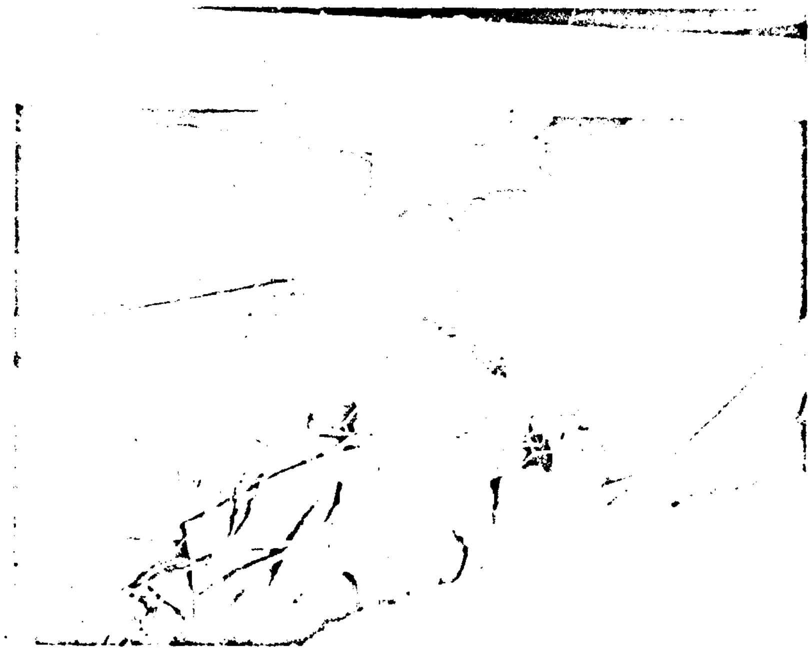

Fig. C.119 Fortification No. 27, after Shot 9

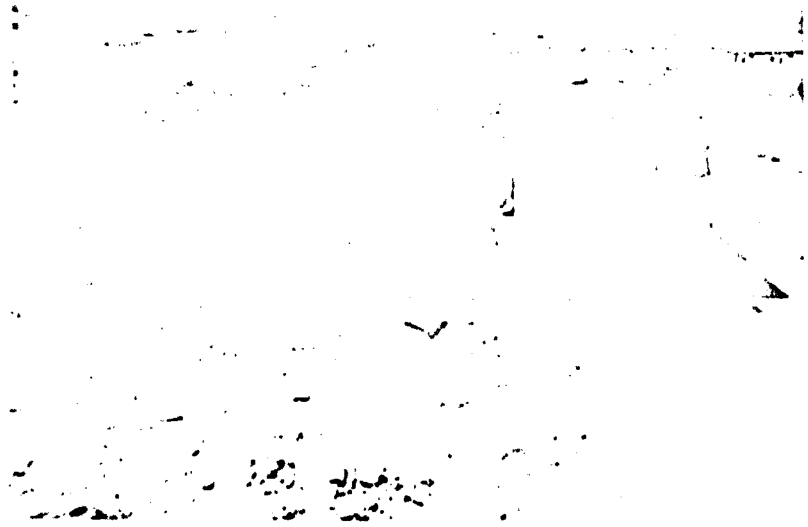

Fig. C.120 Fortification No. 28, before Shot 9

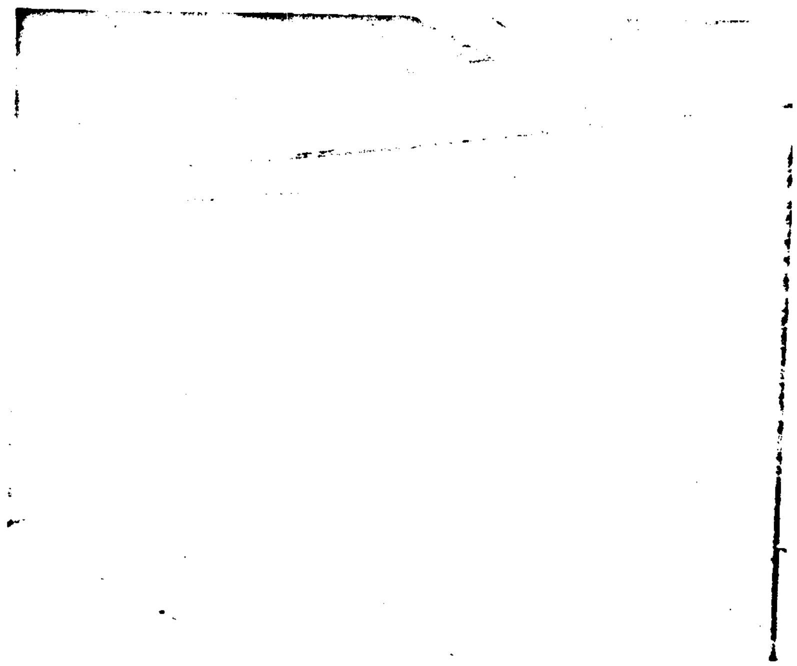

Fig. C.121 Fortification No. 28, before Shot 9

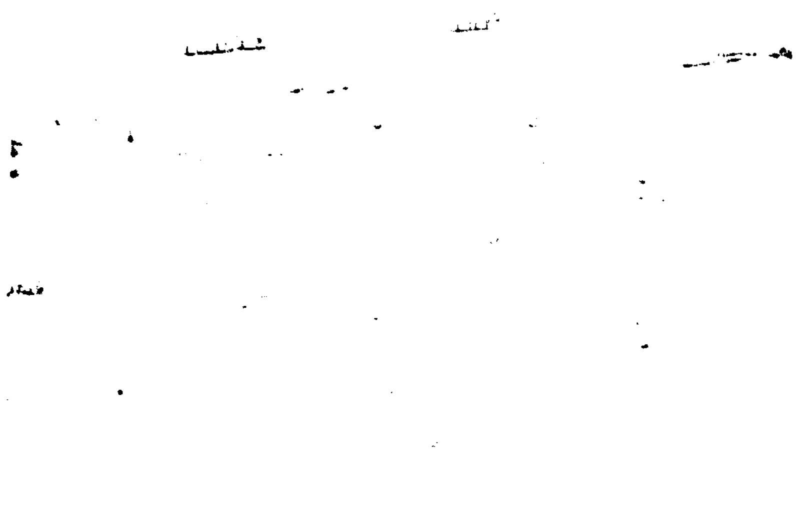

Fig. C.122 Fortification No. 28, after Shot 9

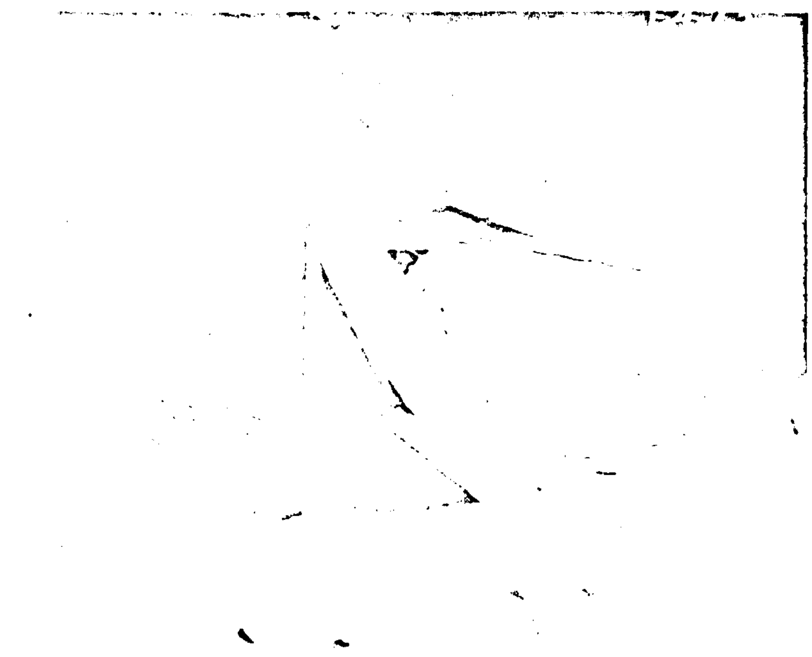

Fig. C.123 Fortification No. 28, after Shot 9

Fig. C.124 Fortification No. 29, before Shot 9

Fig. C.125 Fortification No. 29, before Shot 9

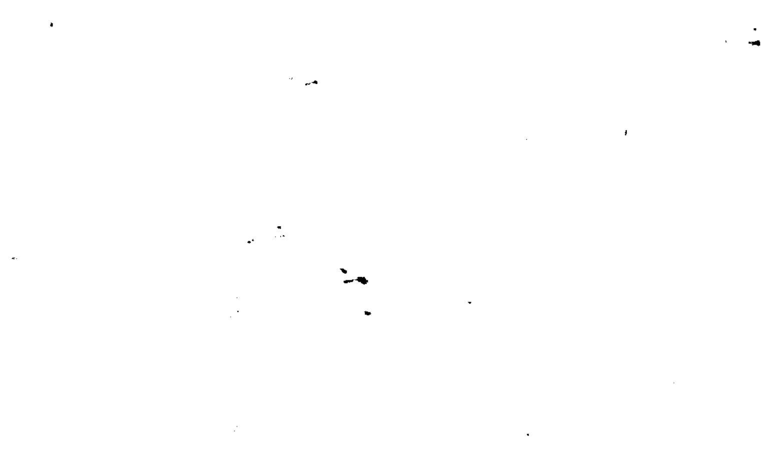

Fig. C.126 Fortification No. 29, after Shot 9

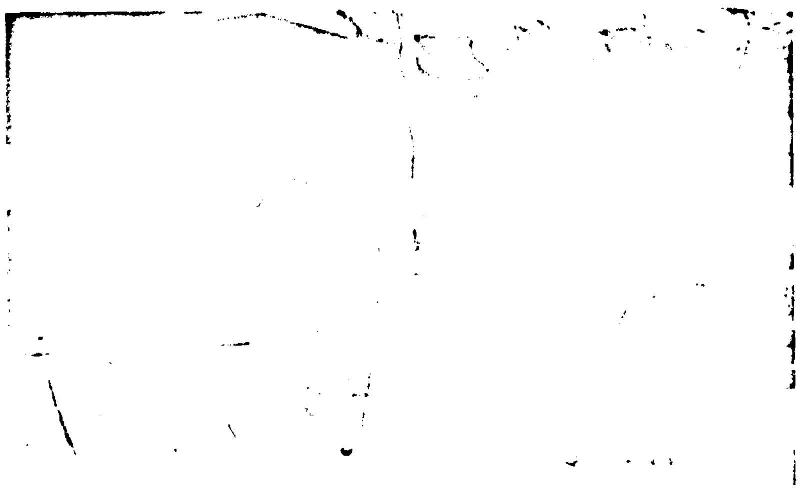

Fig. C.127 Fortification No. 29, after Shot 9

Fig. C.128 Fortification No. 30, before Shot 9

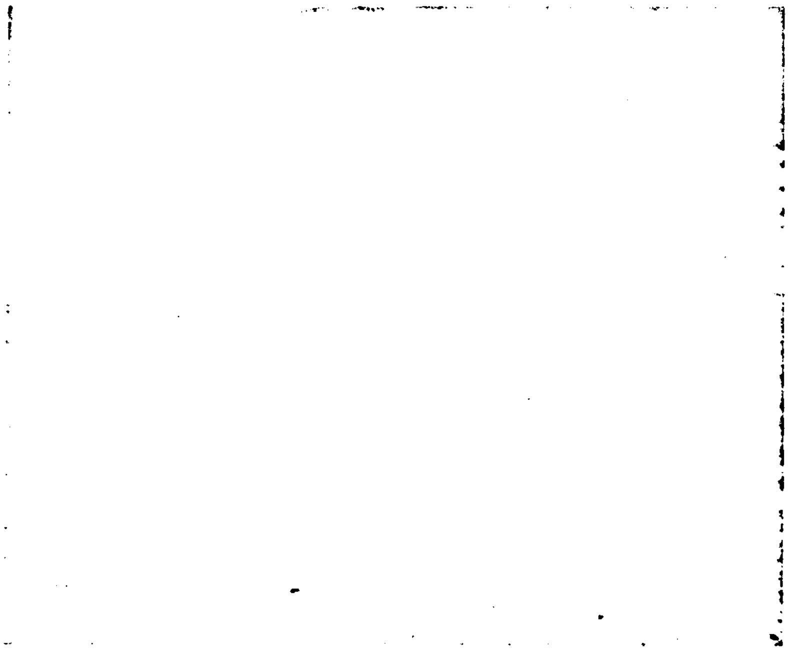

Fig. C.129 Fortification No. 30, before Shot 9

Fig. C.130 Fortification No. 30, after Shot 9

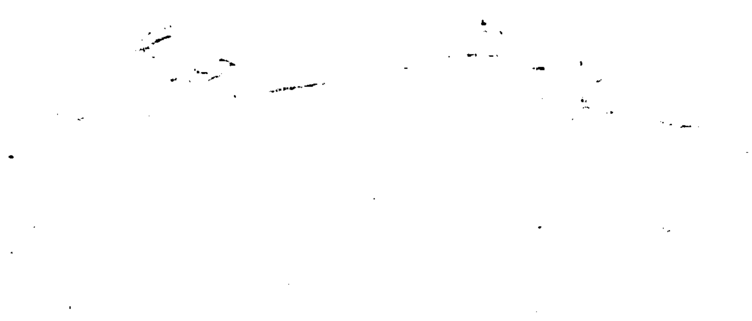

Fig. C.131 Fortification No. 31, after Shot 9

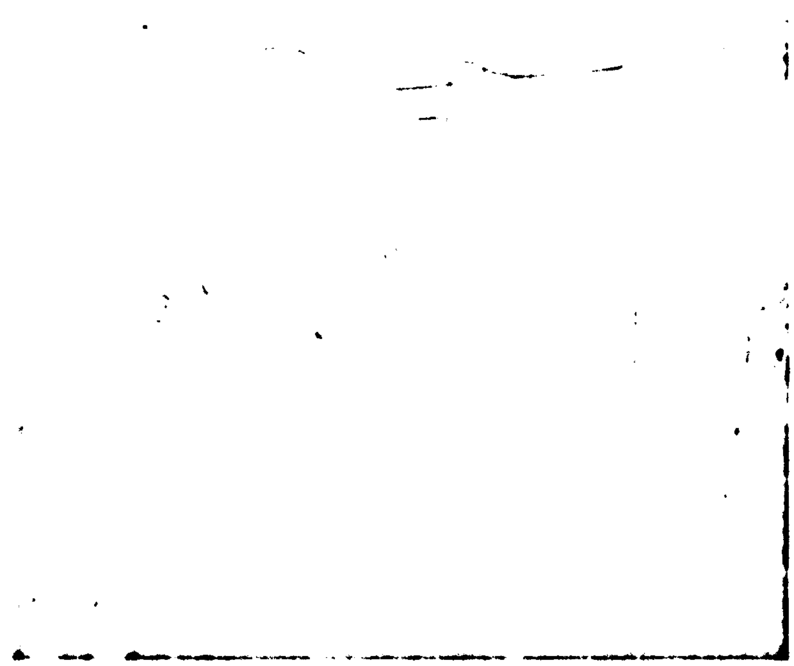

Fig. C.132 Fortification No. 31, after Shot 9

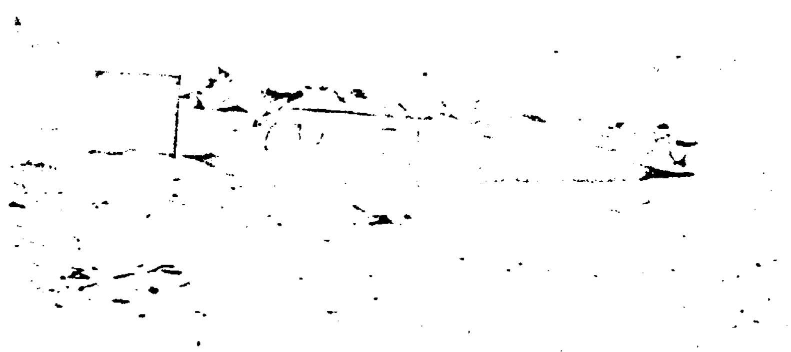

Fig. C.133 Fortification No. 32, after Shot 9

Fig. C.134 Fortification No. 32, after Shot 9

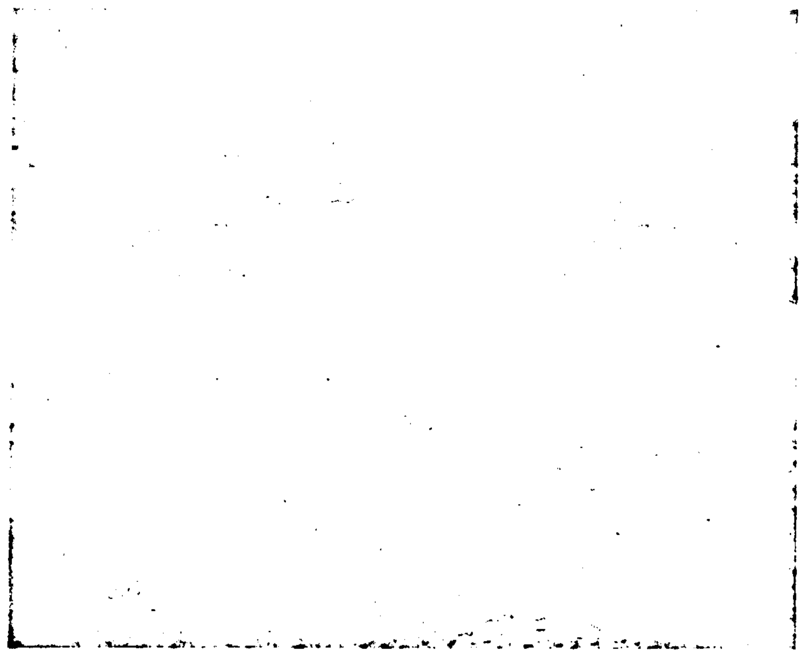

Fig. C.135 Fortification No. 33, before Shot 9

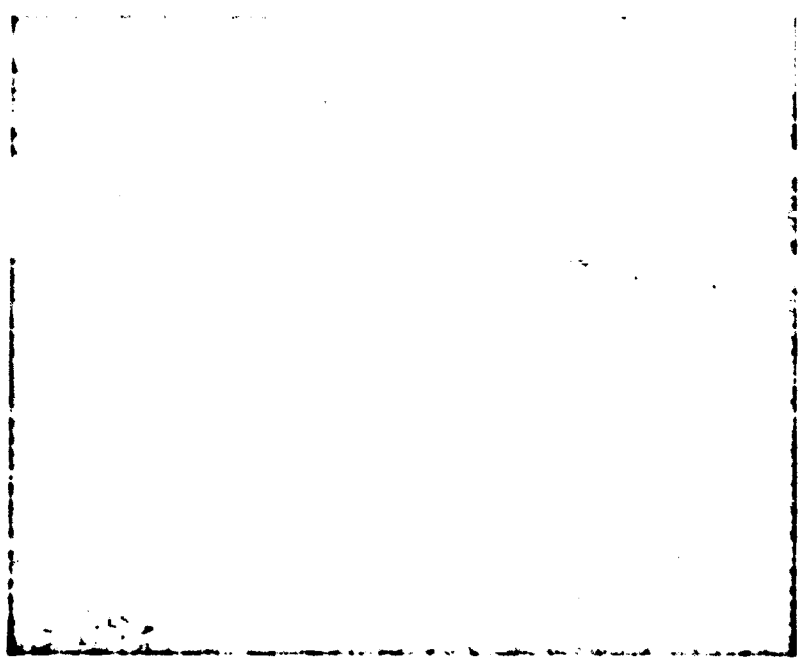

Fig. C.136 Fortification No. 33, before Shot 9

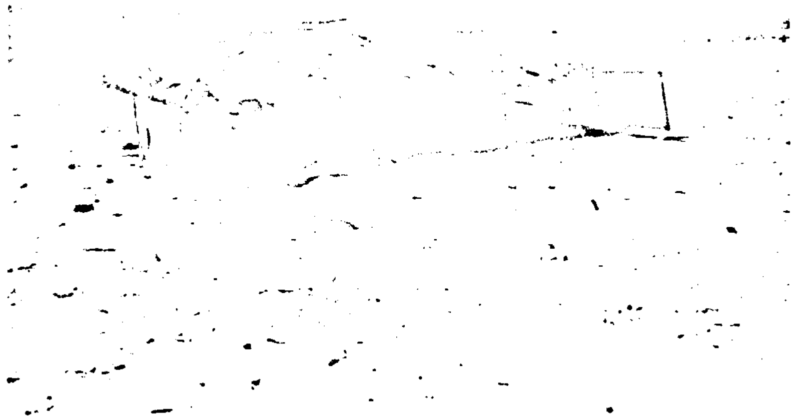

Fig. C.137 Fortification No. 33, after Shot 9

Fig. C.138 Fortification No. 34, before Shot 9

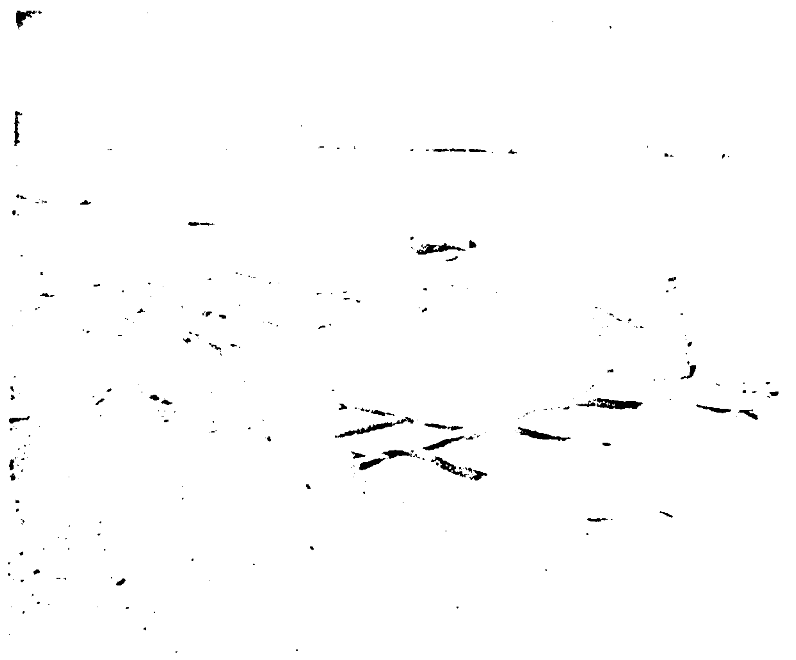

Fig. C.139 Fortification No. 34, after Shot 9

Fig. C.140 Fortification No. 35, before Shot 9

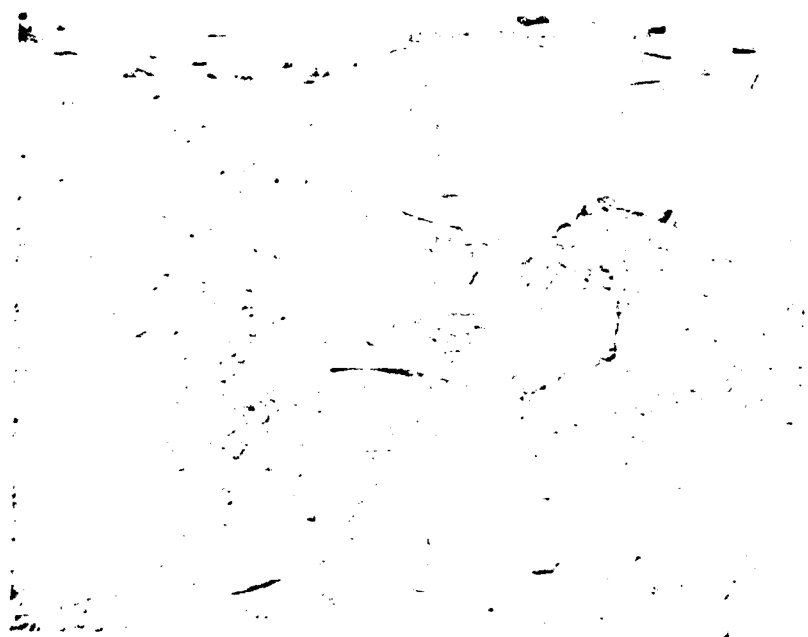

Fig. C.141 Fortification No. 35, after Shot 9

Fig. C.142 Fortification No. 36, before Shot 9

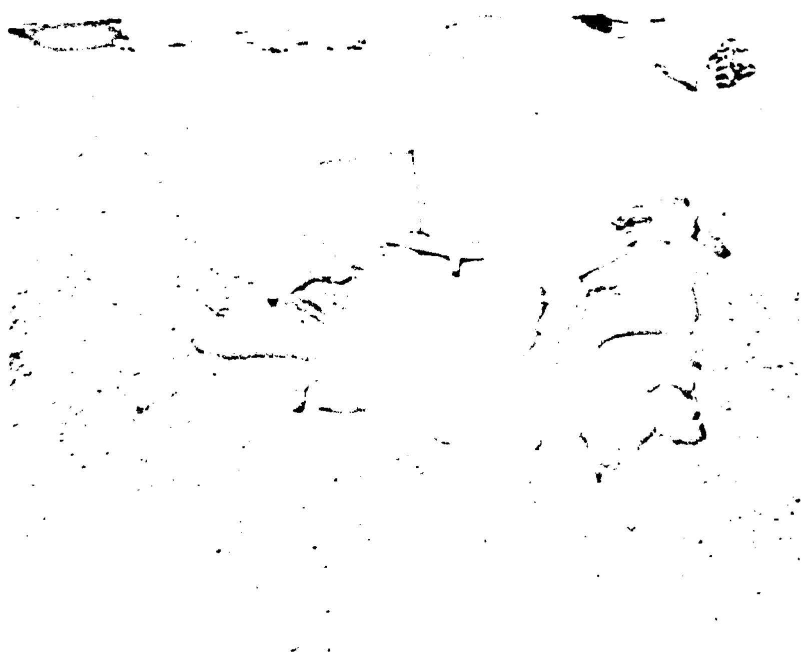

Fig. C.143 Fortification No. 36, after Shot 9

Fig. C.144 Fortification No. 37, before Shot 9

Fig. C.145 Fortification No. 37, after Shot 9

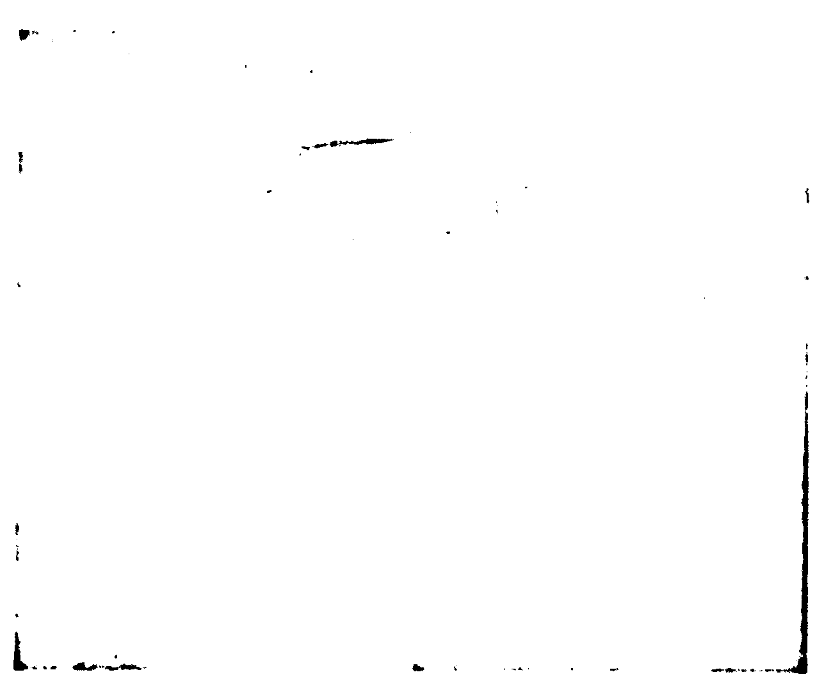

Fig. C.146 Fortification No. 37, after Shot 9

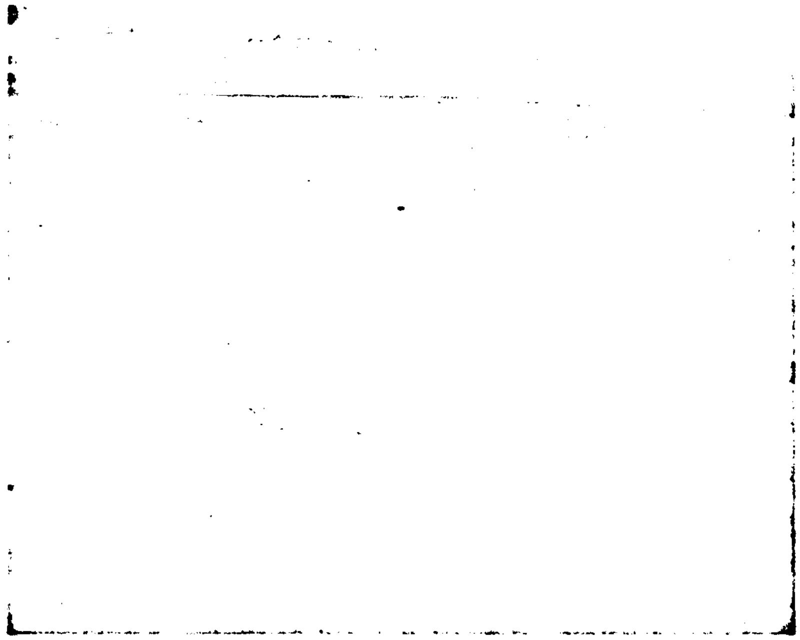

Fig. C.147 Fortification No. 38, before Shot 9

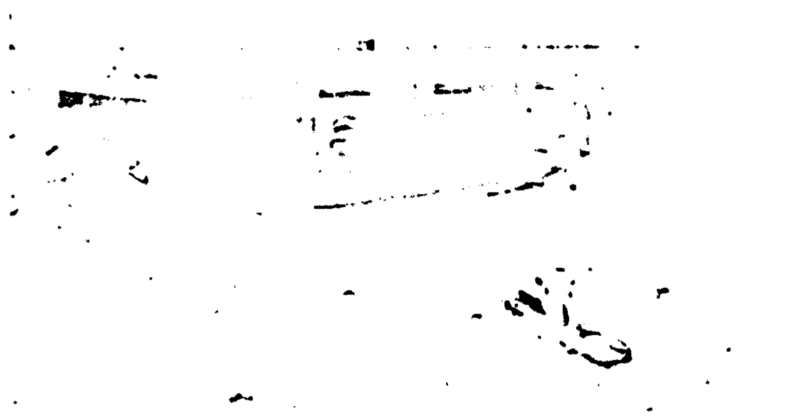

Fig. C.148 Fortification No. 38, after Shot 9

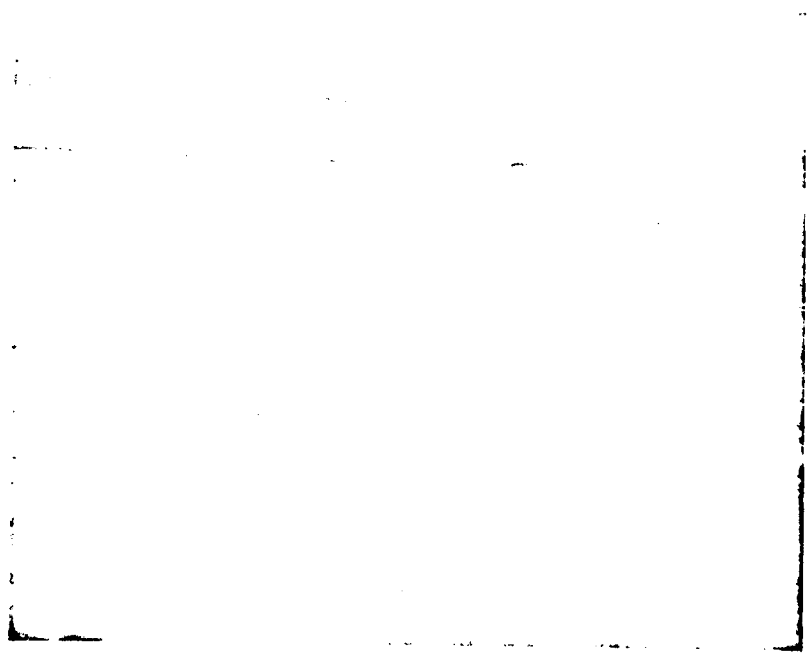

Fig. C.149 Fortification No. 39, before Shot 9

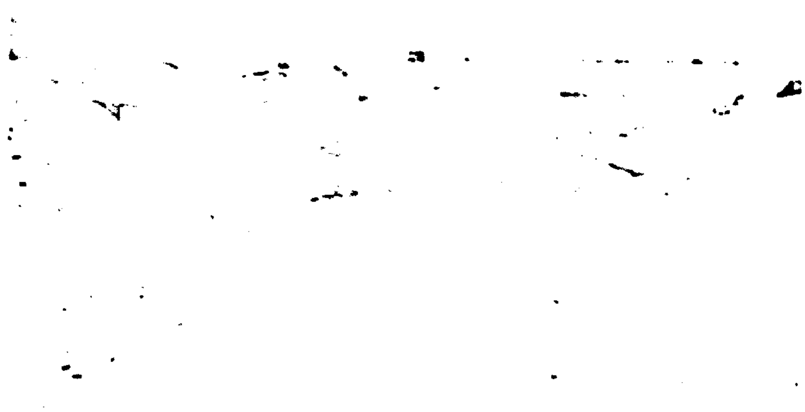

Fig. C.150 Fortification No. 39, after Shot 9

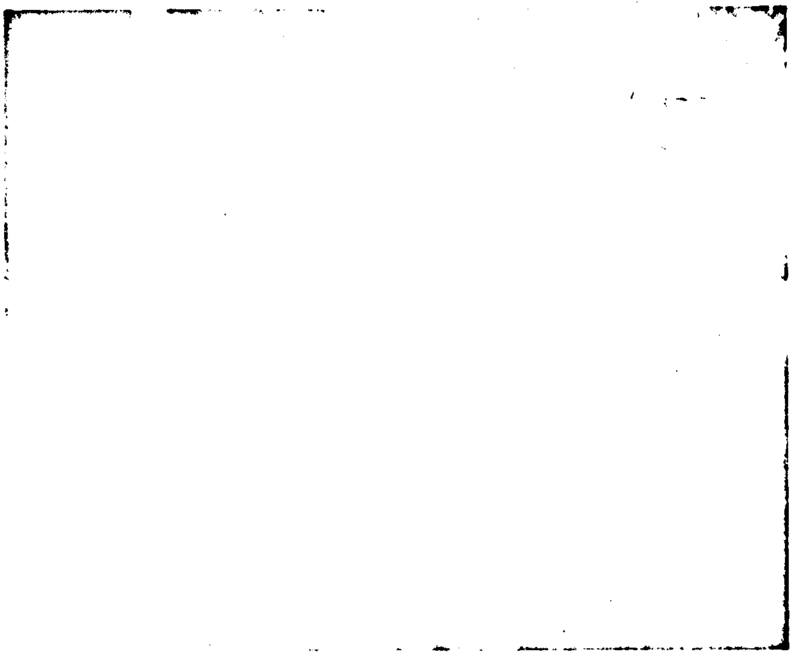

Fig. C.151 Fortification No. 39, after Shot 9

Fig. C.152 Fortification No. 40, before Shot 9

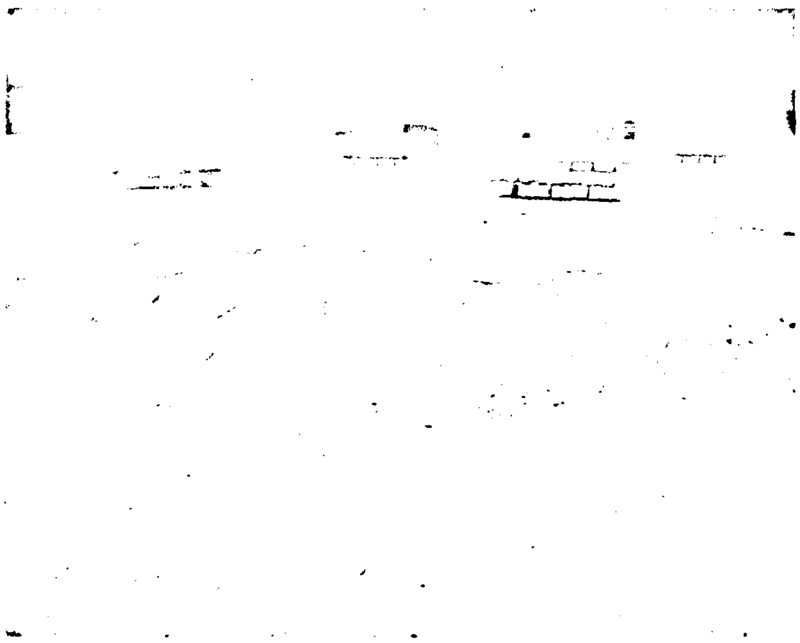

Fig. C.153 Fortification No. 40, before Shot 9

Fig. C.154 Fortification No. 40, after Shot 9

Fig. C.155 Fortification No. 40, after Shot 9

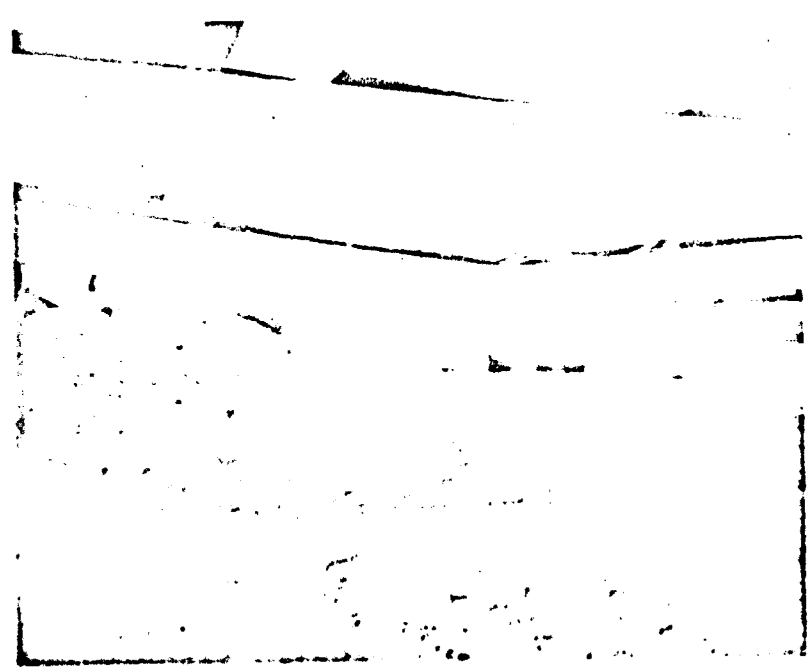

Fig. C.156 Fortification No. 40, after Shot 9

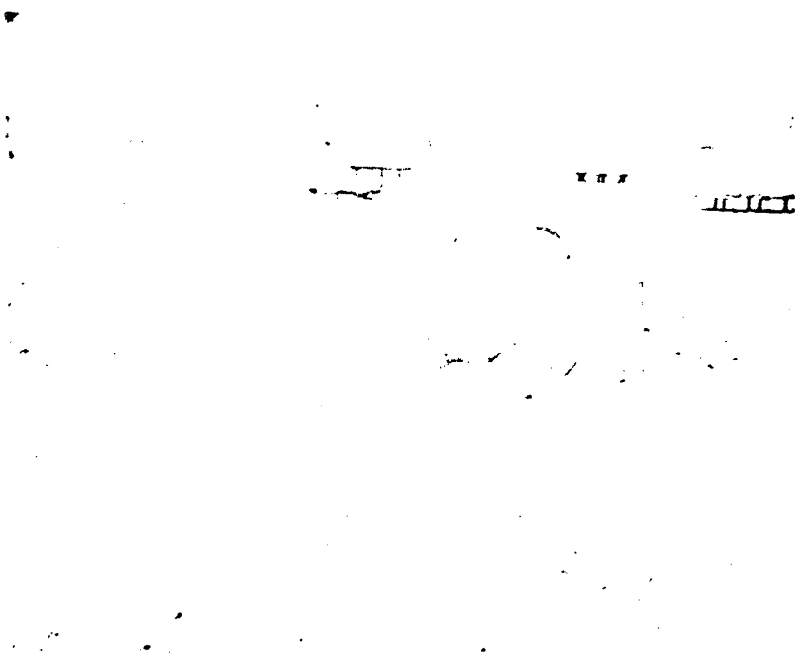

Fig. C.157 Fortification No. 41, before Shot 9

Fig. C.158 Fortification No. 41, before Shot 9

Fig. C.159 Fortification No. 41, after Shot 9

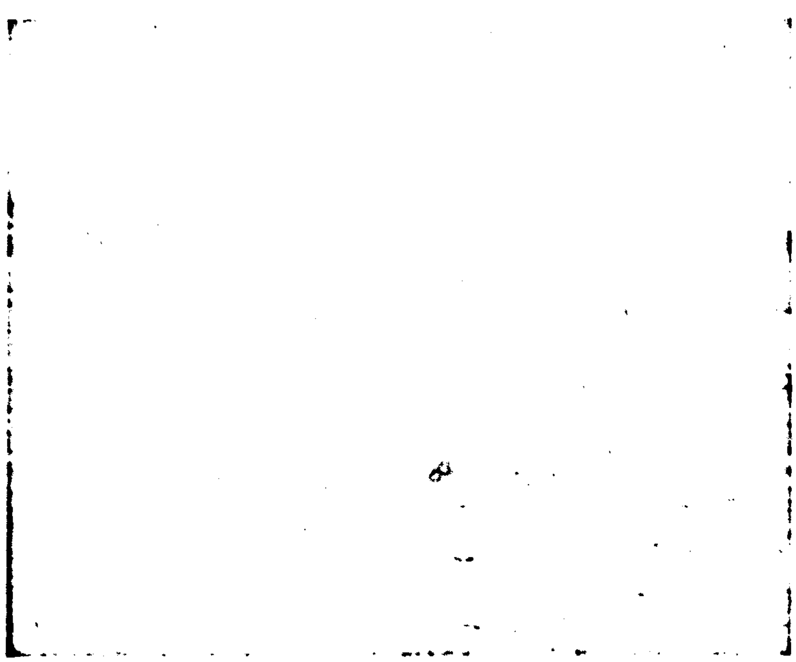

Fig. C.160 Fortification No. 42, before Shot 9

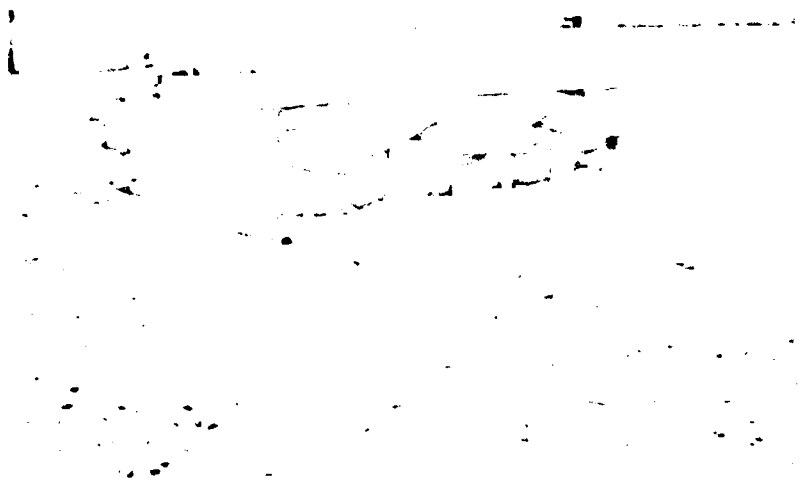

Fig. C.161 Fortification No. 42, after Shot 9

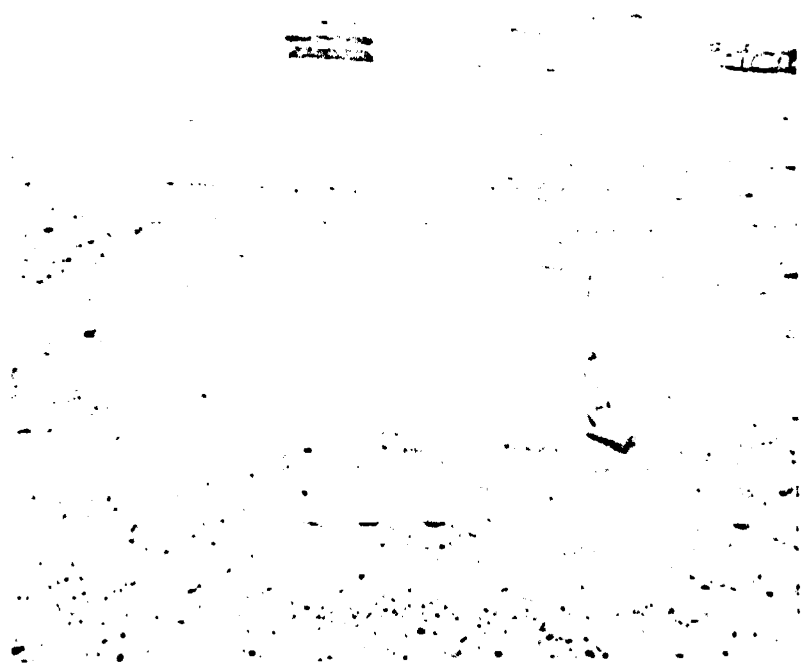

Fig. C.162 Fortification No. 43, before Shot 9

Fig. C.163 Fortification No. 43, after Shot 9

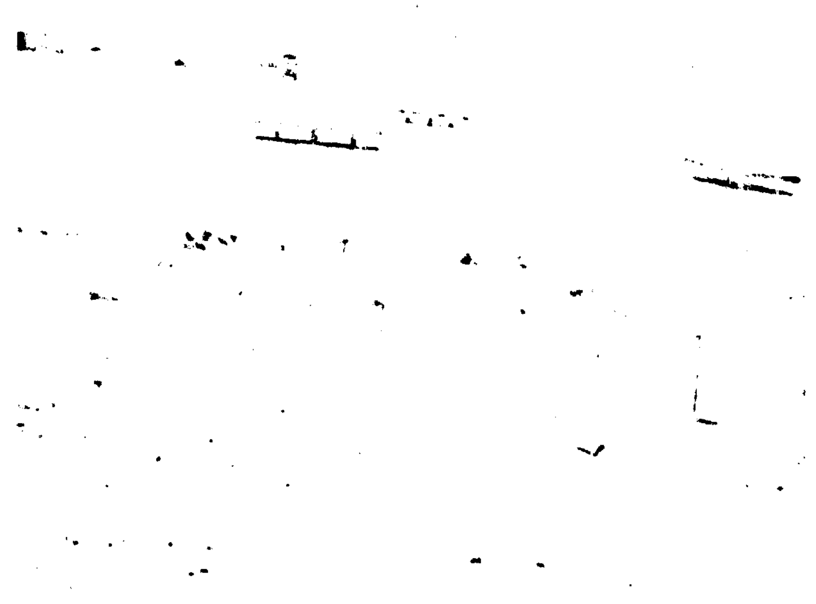

Fig. C.164 Fortification No. 44, before Shot 9

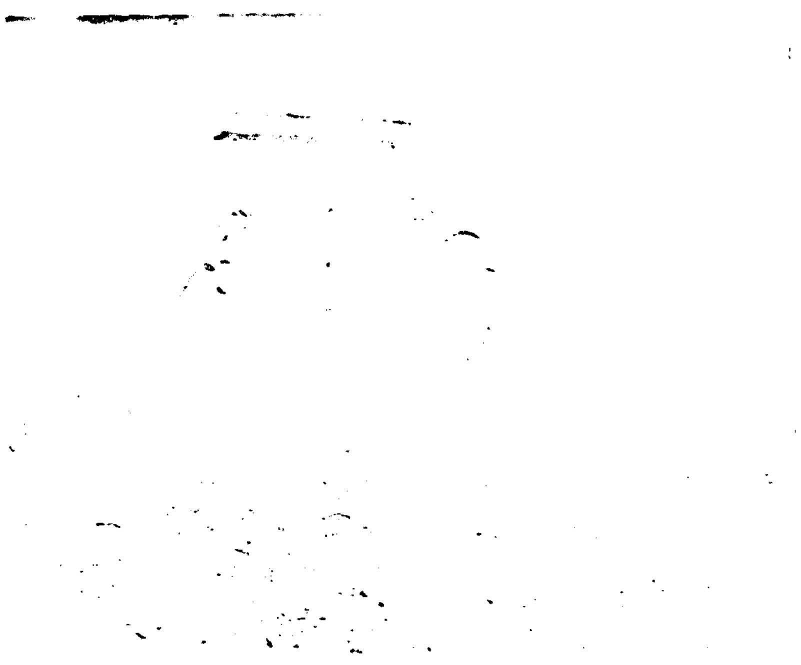

Fig. C.165 Fortification No. 44, before Shot 9

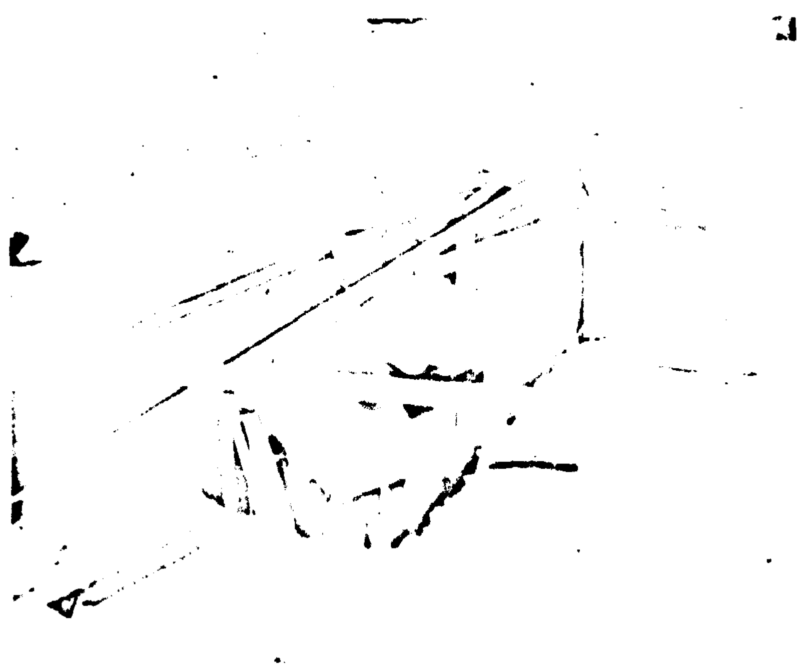

Fig. C.166 Fortification No. 44, after Shot 9

Fig. C.167 Fortification No. 45, before Shot 9

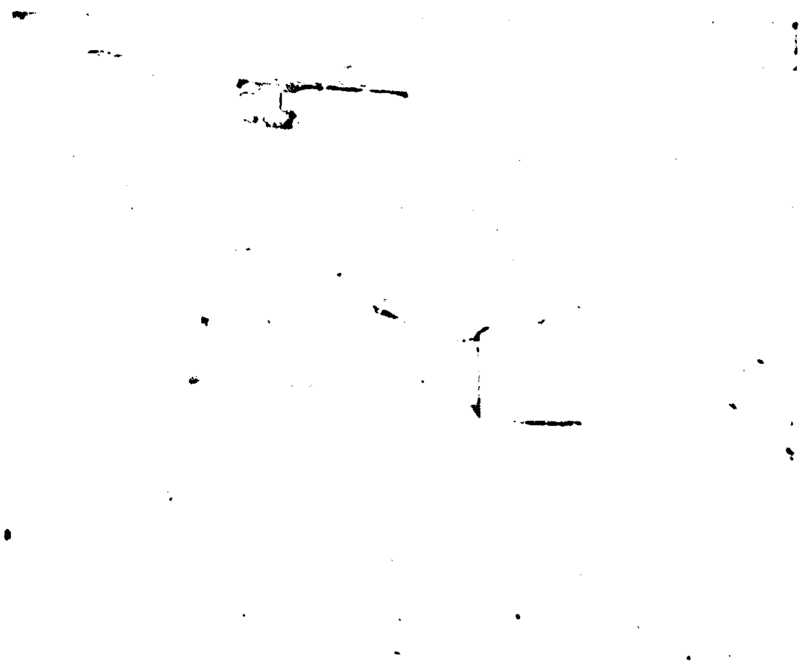

Fig. C.168 Fortification No. 45, before Shot 9

Fig. C.169 Fortification No. 45, after Shot 9

Fig. C.170 Fortification No. 46, before Shot 9

Fig. C.171 Fortification No. 46, after Shot 9

Fig. C.172 Fortification No. 47, before Shot 9

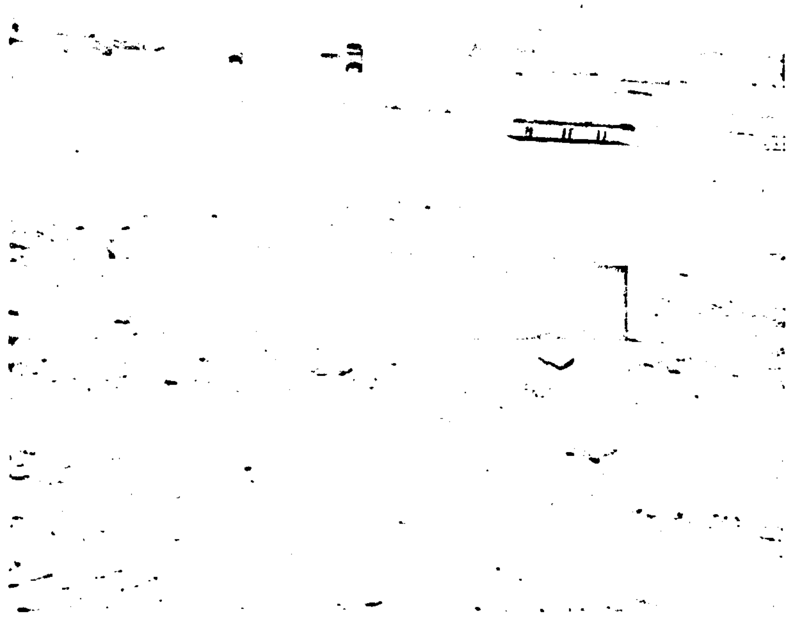

Fig. C.173 Fortification No. 47, after Shot 9

Fig. C.174 Fortification No. 48, before Shot 9

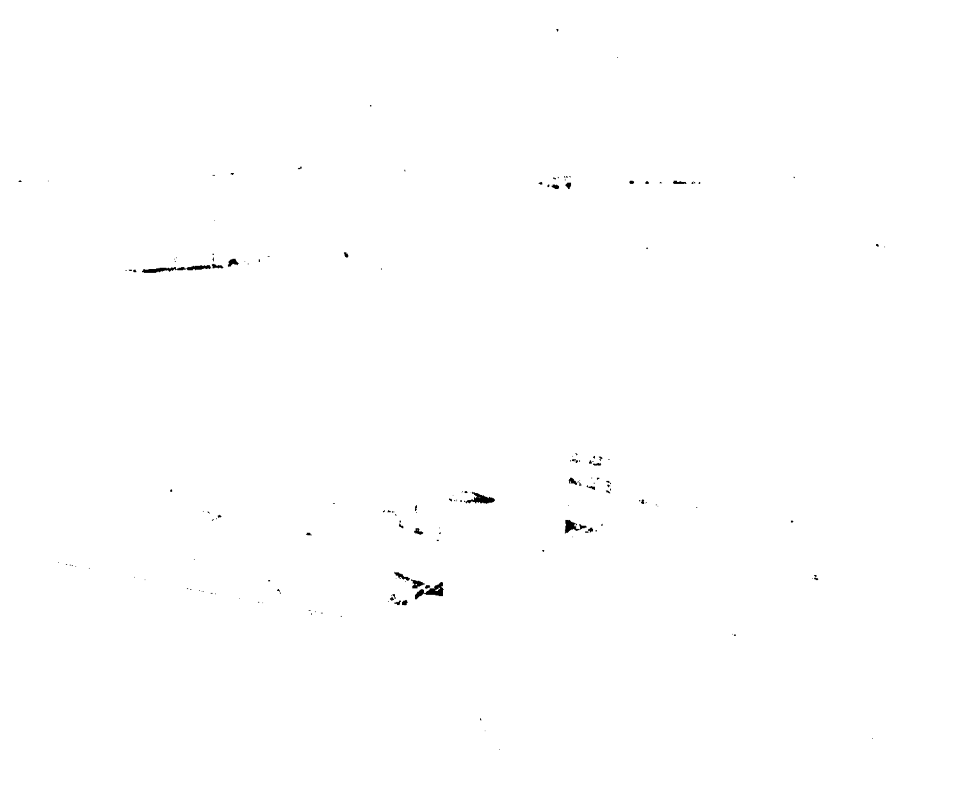

Fig. C.175 Fortification No. 48, after Shot 9

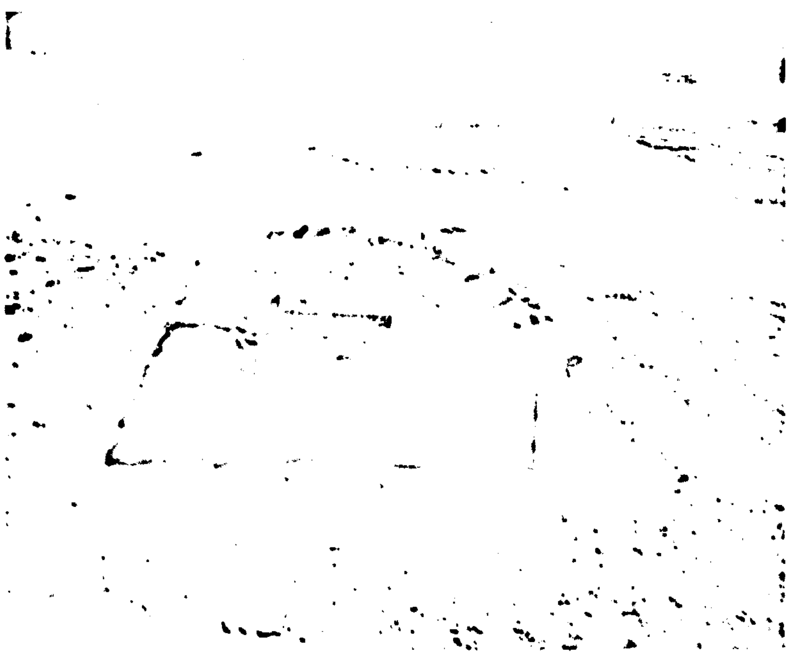

Fig. C.176 Fortification No. 49, before Shot 9

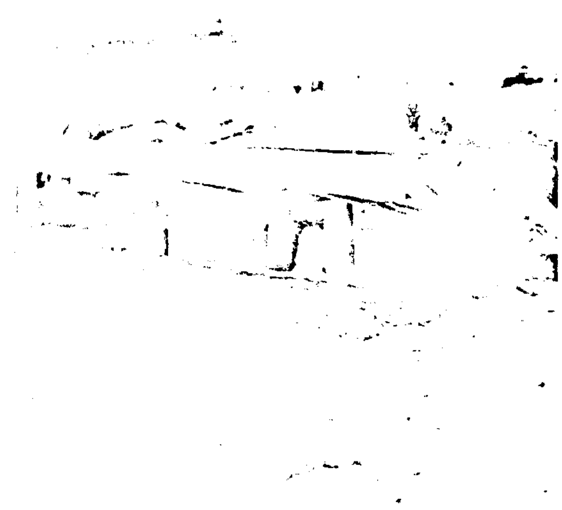

Fig. C.177 Fortification No. 49, after Shot 9

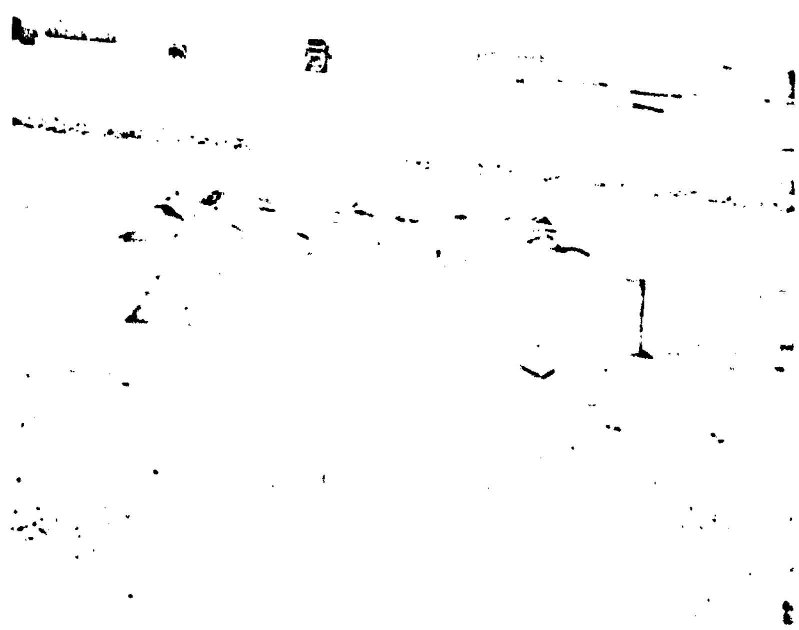

Fig. C.178 Fortification No. 50, before Shot 9

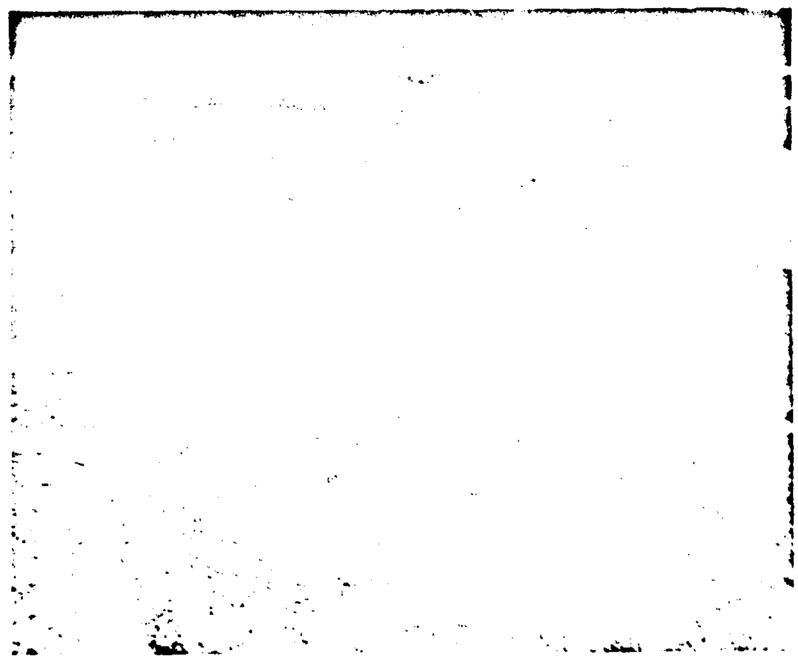

Fig. C.179 Fortification No. 50, before Shot 9

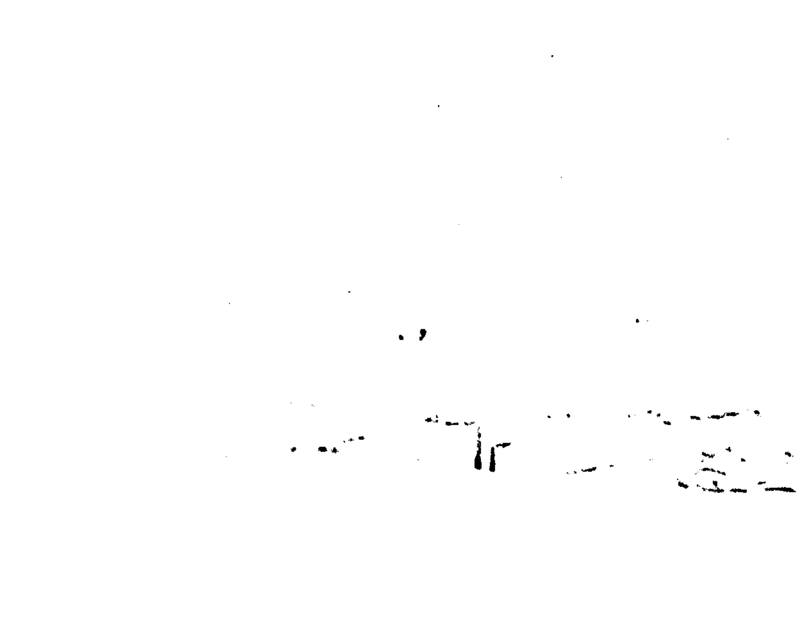

Fig. C.180 Fortification No. 50, after Shot 9

APPENDIX D

GENERAL METHOD OF
DETERMINING THE THERMAL ENERGY RECEIVED IN AN EMPLACEMENT

D.1 INTRODUCTION

Refer to Figs. 13.1 to 13.4, which are the curves for the foxholes in which the receivers were vertical and 1 ft, 1.5 ft, and 3 ft from the directly exposed wall; and note that all the curves corresponding to the incident energy 1 ft down the directly exposed wall are of similar shape and location on the graphs. This is also true for the cases in which the incident energy is 2 ft and 3 ft down the directly exposed wall. Thus, from Figs. 13.1 to 13.4, it was possible to form three generalized curves corresponding to the incident energy 1 ft, 2 ft, and 3 ft down the directly exposed wall.

These three new curves were found to be of such shape and location that it would be possible to further combine them into one completely generalized curve by displacement of each in a horizontal direction. This curve, multiplied by reflectances of 0.30, 0.20, and 0.10, is labeled "C" in Fig. D.1.

In the formation of this generalized curve, it was calculated that an average error of ± 25 per cent was introduced.

D.2 DEFINITIONS OF SYMBOLS

The following symbols are used in Fig. D.1:

D - Distance from ground zero (ft)

HB - Height of burst (ft)

l - Dimension of the emplacement as measured along a radial line from ground zero (ft)

h - Depth in emplacement at which the energy value is desired (ft)

P - Reflectance of the directly exposed wall (taken as 0.10, 0.20, and 0.30 for this case)

D.3 ASSUMPTIONS AND CONDITIONS

The visibility is 20 miles.

The receiver is between 1 ft and 3 ft from the directly exposed wall, and is between 1 ft and 4 ft from the top of the emplacement, and at least 1 ft from either side.

The receiver is vertical.

The exposed wall is perpendicular to a radial line from ground zero.

The relative values of HB, D, and l must be such that (HB x l)/D (distance down the back wall which is exposed to direct thermal radiation) must equal between 1 ft and 3 ft. This corresponds to the direct energy incident from 1 ft to 3 ft down the back wall.

The h must be equal to or greater than (HB x l)/D.

D.4 APPLICATION

Given the values of D, HB, and KT yield for the bomb, determine the total incident thermal energy by using section "A" of Fig. D.1. If visibility is other than 20 miles, it is suggested that TM 23-200 be used to find the total incident thermal energy at the given distance from ground zero.

Using section "B" of Fig. D.1, the same D and HB as above, and then l and h, determine a point on the abscissa of section "C."

Using section "C," along with the points found in sections "A" and "B," determine the energy at depth "h" in the emplacement for a given reflectance.

APPENDIX E

TABLE E.1 - POSITION AND USE OF EACH THERMAL FOXHOLE

Foxhole	Distance From Expected G.Z. (Ft)	Position	Expected Wall Area Exposed (Ft2)	Function
1	4000	Long edge parallel to a radial line from bomb	2	Energy distribution 1 ft from top of foxhole Energy distribution 1.5 ft from exposed wall
2	4000	Long edge parallel to a radial line from bomb	4	Energy distribution 2 ft from top of foxhole Energy distribution 1.5 ft from exposed wall
3	4000	Long edge parallel to a radial line from bomb	6	Energy distribution 3 ft from top of foxhole Energy distribution 1.5 ft from exposed wall
4	4000	Long edge parallel to a radial line from bomb	2	Energy distribution 3 ft from exposed wall
5	4000	Long edge parallel to a radial line from bomb	4	Energy distribution 3 ft from exposed wall
6	4000	Long edge parallel to a radial line from bomb	6	Energy distribution 3 ft from exposed wall

TABLE E.1 - POSITION AND USE OF EACH THERMAL FOXHOLE (CONTINUED)

Foxhole	Distance From Expected G.Z. (Ft)	Position	Expected Wall Area Exposed (Ft^2)	Function
7	4000	Long edge parallel to a radial line from bomb	2	Energy distribution 4.5 ft from exposed wall
8	4000	Long edge parallel to a radial line from bomb	4	Energy distribution 4.5 ft from exposed wall
9	4000	Long edge parallel to a radial line from bomb	6	Energy distribution 4.5 ft from exposed wall
10	4000	Long edge parallel to a radial line from bomb	6	Energy distribution 3 ft from top of foxhole Walls and floor painted black
11	6000	Long edge parallel to a radial line from bomb	6	Verify scaling assumptions Check passive indicators with calorimeters
12	4000	Long edge perpendicular to a radial line from the bomb	6	Energy distribution 1 ft from exposed wall
13	4000	Long edge perpendicular to a radial line from the bomb	12	Energy distribution 1 ft from exposed wall
14	4000	Long edge perpendicular to a radial line from the bomb	18	Energy distribution 1 ft from exposed wall

TABLE E.1 - POSITION AND USE OF EACH THERMAL FOXHOLE
(CONTINUED)

Foxhole	Distance From Expected G.Z. (Ft)	Position	Expected Wall Area Exposed (Ft^2)	Function
15	6000	Long edge perpendicular to a radial line from the bomb	Shot 9 - 18 Shot 10 - 12	Energy distribution 1 ft from exposed wall
16	8000	Long edge perpendicular to a radial line from the bomb	12	Energy distribution 1 ft from exposed wall Verify scaling assumptions Check passive indicators with calorimeters
17	4000	Long edge parallel to a radial line from bomb	2	Energy distribution 2 ft from top of foxhole
18	4000	Long edge parallel to a radial line from bomb	2	Energy distribution 3 ft from top of foxhole
19	4000	Long edge parallel to a radial line from bomb	4	Energy distribution 3 ft from top of foxhole
20	4000	Long edge parallel to a radial line from bomb	8	Energy distribution 4 ft from exposed wall
21	4000	Long edge perpendicular to a radial line from the bomb	24	Energy distribution 1 ft from exposed wall
22	4000	Long edge parallel to a radial line from bomb	8 plus 4 of the floor	Energy distribution 4 ft from exposed wall

APPENDIX F

TABLE F.1 - THERMAL DATA

Foxhole: 1
Receiver Position: Horizontal
Predicted Wall Area Exposed: 2 ft^2

Shot	Distance From: Exposed Wall (Ft)	Distance From: Top (Ft)	Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
9	2.31	1.0	1.18	0.77	0.0211	2.42	0.0510
	2.19			0.84	0.0230		0.0556
	1.81			2.4	0.0658		0.159
	1.56			3.0	0.0822		0.199
10	2.56	1.0	2.02	0.45	0.0184	1.42	0.0261
	2.31			0.62	0.0253		0.0359
	2.06			1.58	0.0645		0.0915
	1.94			1.1	0.0449		0.0638
	1.69			1.92	0.0785		0.112

TABLE F.2 Thermal Data

Foxhole: 1
Receiver Position: Vertical
Predicted Wall Area Exposed: 2 ft^2

Shot	Distance From: Exposed Wall (Ft)	Distance From: Top (Ft)	Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
9	1.5	1.63	1.18	3.0	0.0822	2.42	0.199
		1.75		2.4	0.0658		0.159
		1.88		0.62	0.0170		0.0411
10	1.5	1.30	2.02	12	0.490	1.42	0.696
		1.43		9.7	0.396		0.562
		1.55		7.1	0.290		0.411
		1.68		5.6	0.229		0.325

TABLE F.3 Thermal Data

Foxhole: 2
Receiver Position: Horizontal
Predicted Wall Area Exposed: 4 ft^2

Shot	Distance From: Exposed Wall (Ft)	Distance From: Top (Ft)	Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
9	5.44	2.0	2.85	0.62	0.0170	2.0	0.0340
	3.94			0.84	0.0230		0.0460
	3.19			2.4	0.0658		0.132
10	4.44	2.0	3.70	0.62	0.0253	1.53	0.0387
	4.06			0.77	0.0314		0.0481
	2.69			1.65	0.0673		0.103
	1.56			3.0	0.122		0.187

TABLE F.4 - THERMAL DATA

Foxhole: 2
Receiver Position: Vertical
Predicted Wall Area Exposed: 4 ft^2

Shot	Distance From:		Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
	Exposed Wall (Ft)	Top (Ft)					
9	1.5	2.07	2.85	7.1	0.194	2.00	0.390
		2.19		5.6	0.153		0.306
		2.95		1.1	0.0302		0.0604
		3.07		0.45	0.0123		0.0246
		3.20		0.77	0.0211		0.0422
		3.32		0.62	0.0170		0.0340
10	1.5	2.21	3.70	12	0.490	1.53	0.750
		2.84		9.7	0.396		0.606
		2.96		6.3	0.257		0.393
		3.34		3.0	0.122		0.187
		3.46		1.1	0.0449		0.0688
		3.59		0.84	0.0343		0.0525
		3.71		0.45	0.0384		0.0282

TABLE F.5 - THERMAL DATA

Foxhole: 3
Receiver Position: Horizontal
Predicted Wall Area Exposed: 6 ft^2

Shot	Distance From:		Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
	Exposed Wall (Ft)	Top (Ft)					
9	5.44	3	4.10	0.77	0.0211	2.07	0.0436
	4.94			0.45	0.0123		0.0254
	4.69			0.84	0.0230		0.0476
	3.81			1.1	0.0301		0.0622
	1.69			7.1	0.195		0.404
	1.56			9.7	0.266		0.550
10	5.31	3	5.60	0.62	0.0253	1.54	0.0389
	4.81			0.77	0.0314		0.0484
	4.06			0.84	0.0343		0.0528
	3.81			0.45	0.0184		0.0283
	3.05			1.1	0.0449		0.0691
	1.69			5.6	0.229		0.352
	1.56			7.1	0.290		0.447

TABLE F.6 - THERMAL DATA

Foxhole: 3
Receiver Position: Vertical
Predicted Wall Area Exposed: 6 ft^2

Shot	Distance From: Exposed Wall (Ft)	Distance From: Top (Ft)	Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
9	1.5	3.13	4.10	7.1	0.194	2.07	0.402
		3.51		5.6	0.153		0.317
		3.76		5.6	0.153		0.317
10	1.5	3.26	5.60	12	0.490	1.51	0.740
		3.39		9.7	0.396		0.597
		3.51		7.1	0.290		0.438
		3.76		5.6	0.229		0.346
		3.89		3.0	0.122		0.184

TABLE F.7 — THERMAL DATA

Foxhole: 4
Receiver Position: Vertical
Predicted Wall Area Exposed: 2 ft^2

Shot	Distance From:		Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
	Exposed Wall (Ft)	Top (Ft)					
9	3	1.25	1.18	7.1	0.194	2.42	0.470
		1.63		5.6	0.153		0.370
		1.88		3.0	0.0822		0.199
		2.13		2.4	0.0658		0.159
		2.25		0.45	0.0123		0.0298
		2.38		0.77	0.0211		0.0510
		2.63		0.62	0.0170		0.0412
10	3	1.22	1.61	7.1	0.290	1.71	0.496
		1.60		5.6	0.229		0.391
		2.22		3.0	0.122		0.208
		2.35		0.97	0.0396		0.0674
		2.60		0.45	0.0184		0.0314
		2.72		0.77	0.0314		0.0536
		2.97		0.62	0.0253		0.0432

TABLE F.8 - THERMAL DATA

Foxhole: 5
Receiver Position: Vertical
Predicted Wall Area Exposed: 4 ft^2

Shot	Distance From:		Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
	Exposed Wall (Ft)	Top (Ft)					
9	3	2.11	2.79	12	0.329	2.04	0.671
		2.36		9.7	0.266		0.543
		2.61		7.1	0.194		0.396
		2.74		5.6	0.153		0.312
		3.36		3.0	0.0822		0.168
		3.74		1.1	0.0302		0.0616
10	3	2.46	3.70	12	0.490	1.53	0.750
		2.71		9.7	0.396		0.606
		3.21		7.1	0.290		0.444
		3.71		5.6	0.229		0.350

TABLE F.9 - THERMAL DATA

Foxhole: 6
Receiver Position: Vertical
Predicted Wall Area Exposed: 6 ft^2

Shot	Distance From: Exposed Wall (Ft)	Distance From: Top (Ft)	Actual Wall Area Exposed (Ft2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
9	3	2.04	4.23	12	0.329	2.02	0.664
		2.54		9.7	0.266		0.536
		3.29		7.1	0.194		0.398
		3.42		5.6	0.153		0.309
10	3	2.26	5.60	12	0.490	1.52	0.745
		2.76		12	0.490		0.745
		3.01		9.7	0.396		0.602
		3.76		7.1	0.290		0.441
		3.89		5.6	0.229		0.348

TABLE F.10 - THERMAL DATA

Foxhole: 7
Receiver Position: Vertical
Predicted Wall Area Exposed: 2 ft^2

Shot	Distance From: Exposed Wall (Ft)	Distance From: Top (Ft)	Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
9	4.5	1.11	1.39	2.4	0.0658	2.06	0.135
		1.61		0.84	0.0230		0.0474
		1.74		0.77	0.0211		0.0434
		1.86		0.62	0.0170		0.0350
10	4.5	1.22	1.67	2.4	0.0980	1.72	0.169
		1.72		0.84	0.0343		0.0590

TABLE F.11 - THERMAL DATA

Foxhole: 8
Receiver Position: Vertical
Predicted Wall Area Exposed: 4 ft^2

Shot	Distance From: Exposed Wall (Ft)	Distance From: Top (Ft)	Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
9	4.5	1.0 - 4.0	2.95	3.0 - 5.6	0.0822-0.153	1.93	0.159-0.295
10	4.5	1.0 - 4.0	3.70	3.0 - 5.6	0.122-0.229	1.53	0.187-0.350

TABLE F.12 - THERMAL DATA

Foxhole: 9
Receiver Position: Vertical
Predicted Wall Area Exposed: 6 ft^2

Shot	Distance From:		Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
	Exposed Wall (Ft)	Top (Ft)					
9	4.5	1.0 - 4.0	4.05	3.0 - 5.6	0.0822-0.153	2.10	0.173 -0.321
10	4.5	1.0 - 4.0	5.72	3.0 - 5.6	0.122-0.229	1.49	0.182-0.341

TABLE F.13 - THERMAL DATA

Foxhole: 10
Receiver Position: Horizontal
Predicted Wall Area Exposed: 6 ft^2

Shot	Distance From:		Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Correction Factor	Corrected Fraction
	Exposed Wall (Ft)	Top (Ft)					
9	4.44	3	4.16	0.62	0.0170	2.06	0.0350
	3.44			0.62	0.0170		0.0350
	2.44			1.16	0.0318		0.0655
	1.81			1.1	0.0302		0.0621
10	4.31	3	5.46	0.62	0.0253	1.56	0.0395
	3.44			0.62	0.0253		0.0395
	2.69			0.84	0.0343		0.0535
	2.56			1.1	0.0449		0.0700

TABLE F.14 - THERMAL DATA

Foxhole: 11
Receiver Position: Horizontal
Predicted Wall Area Exposed: 6 ft^2

Shot	Distance From: Exposed Wall (Ft)	Distance From: Top (Ft)	Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
9	4.44	3.0	4.86	0.62	0.0282	1.76	0.0496
	3.44			0.61	0.0277		0.0487
	3.06			2.4	0.109		0.192
	2.94			1.1	0.0500		0.0880
	2.81			0.84	0.0382		0.0673
	2.69			3.0	0.136		0.239
10	3.06	3.0	5.10	0.62	0.0516	1.67	0.0862
	2.94			0.77	0.0641		0.107
	2.69			0.45	0.0375		0.0627
	2.44			0.62	0.0516		0.0862
	2.31			0.77	0.0641		0.107

TABLE F.15 - THERMAL DATA

Foxhole: 11
Receiver Position: Vertical
Predicted Wall Area Exposed: 6 ft^2

Shot	Distance From: Exposed Wall (Ft)	Distance From: Top (Ft)	Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
9	4.5	0.99	4.86	0.62	0.0282	1.76	0.0496
		1.12		0.77	0.0350		0.0616
		1.24		0.45	0.0204		0.0359
		1.49		1.45	0.0660		0.116
		2.24		3.0	0.136		0.239
	1.5	3.37		9.7	0.440		0.775
		3.49		5.6	0.255		0.449
		3.62		7.1	0.322		0.566
10	4.5	2.26	5.10	0.62	0.0516	1.67	0.0862
		2.64		0.77	0.0641		0.107
		2.76		0.45	0.0375		0.0627
		3.14		2.4	0.200		0.334
		3.39		0.97	0.0807		0.135
	1.5	3.89		0.97	0.0807		0.135

TABLE F.16 - THERMAL DATA

Foxhole: 12
Receiver Position: Vertical
Predicted Wall Area Exposed: 6 ft^2

Shot	Distance From: Exposed Wall (Ft)	Distance From: Top (Ft)	Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
9	1.0	0.64	7.90	14	0.384	1.08	0.415
		0.77		14	0.384		0.415
		0.89		13	0.356		0.384
		1.02		11	0.302		0.326
		1.14		9.7	0.266		0.287
		1.27		6.3	0.172		0.186
		1.64		2.4	0.0658		0.0710
		1.77		0.81	0.0222		0.0240
		1.89		1.58	0.0432		0.0467
		2.02		0.61	0.0167		0.0180
		2.14		2.4	0.0658		0.0710
		2.27		0.62	0.0170		0.0183
		2.39		0.62	0.0170		0.0183
10	1.0	1.63	4.06	1.65	0.0674	2.10	0.142
		1.76		1.65	0.0674		0.142
		1.88		1.10	0.0449		0.0944
		2.01		1.02	0.0416		0.0874

TABLE F.17 - THERMAL DATA

Foxhole: 13
Receiver Position: Vertical
Predicted Wall Area Exposed: 12 ft^2

Shot	Distance From:		Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
	Exposed Wall (Ft)	Top (Ft)					
9	1.0	2.14	10.8	14	0.383	1.59	0.609
		2.27		13.5	0.370		0.588
		2.39		12	0.329		0.523
		2.57		13	0.356		0.566
		2.64		10.8	0.296		0.470
		2.77		8.4	0.230		0.366
		2.89		6.3	0.172		0.273
		3.02		5.6	0.153		0.243
		3.14		3.0	0.0821		0.131
10	1.0	2.30	11.1	12	0.490	1.53	0.750
		2.43		10.8	0.441		0.675
		2.55		8.4	0.343		0.525
		2.68		6.1	0.249		0.381
		3.05		1.1	0.0449		0.0686
		3.18		0.84	0.0343		0.0525
		3.30		0.84	0.0343		0.0525
		3.55		0.45	0.0184		0.0281

TABLE F.18 - THERMAL DATA

Foxhole: 14
Receiver Position: Vertical
Predicted Wall Area Exposed: 18 ft^2

Shot	Distance From:		Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
	Exposed Wall (Ft)	Top (Ft)					
9	1.0	3.12	14.0	13	0.356	1.83	0.651
		3.37		12	0.329		0.602
		3.50		10.9	0.299		0.547
		3.62		10	0.274		0.501
		3.75		7.1	0.194		0.355
10	1.0	3.30	10.6	7.1	0.290	2.42	0.701
		3.55		7.6	0.310		0.750
		3.68		5.6	0.229		0.554
		3.80		7.1	0.290		0.701

TABLE F.19 - THERMAL DATA

Foxhole: 15
Receiver Position: Vertical
Predicted Wall Area Exposed: Shot 9 - 18 ft^2
Shot 10 - 12 ft^2

Shot	Distance From:		Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
	Exposed Wall (Ft)	Top (Ft)					
9	1.0	3.39	14.1	7.6	0.345	1.81	0.621
		3.52		7.1	0.322		0.580
		3.64		7.1	0.322		0.580
10	1.0	2.39	10.0	3.0	0.250	1.71	0.427
		2.77		1.37	0.114		0.195
		2.89		0.77	0.0641		0.110
		3.02		0.62	0.0516		0.0881
		3.14		0.62	0.0516		0.0881

TABLE F.20 - THERMAL DATA

Foxhole: 16
Receiver Position: Vertical
Predicted Wall Area Exposed: 12 ft^2

Shot	Distance From:		Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
	Exposed Wall (Ft)	Top (Ft)					
9	1.0	2.44	11.9	3.0	0.240	1.43	0.343
		2.69		2.4	0.192		0.274
		2.84		0.97	0.0775		0.111
		3.06		0.62	0.0495		0.0708
10	1.0	1.0 - 4.0	8.58	No indicator reactions		1.99	<0.135

TABLE F.21 - THERMAL DATA

Foxhole: 17
Receiver Position: Horizontal
Predicted Wall Area Exposed: 2 ft^2

Shot	Distance From:		Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
	Exposed Wall (Ft)	Top (Ft)					
9	5.06	2.0	1.18	0.62	0.0170	2.42	0.0411
	4.94			0.77	0.0211		0.0510
	4.56			0.77	0.0211		0.0510
	3.19			0.62	0.0170		0.0411
10	0.5 - 5.5	2.0	1.82	No indicator reactions		1.58	<0.0291

TABLE F.22 — THERMAL DATA

Foxhole: 18
Receiver Position: Horizontal
Predicted Wall Area Exposed: 2 ft^2

Shot	Distance From:		Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
	Exposed Wall (Ft)	Top (Ft)					
9	0.5 - 5.5	3.0	1.43	No indicator reactions		2.04	<0.0251
10	0.5 - 5.5	3.0	1.76	No indicator reactions		1.63	<0.0300

TABLE F.23 - THERMAL DATA

Foxhole: 19
Receiver Position: Horizontal
Predicted Wall Area Exposed: 4 ft^2

Shot	Distance From:		Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
	Exposed Wall (Ft)	Top (Ft)					
9	5.06	3	3.07	0.62	0.0170	1.87	0.0318
	3.69			0.84	0.0230		0.0430
	3.56			0.84	0.0230		0.0430
	3.06			0.62	0.0170		0.0318
	2.94			0.77	0.0211		0.0394
	2.81			0.77	0.0211		0.0394
10	5.31	3	4.04	0.62	0.0253	1.42	0.0359
	4.81			0.62	0.0253		0.0359
	4.44			0.62	0.0253		0.0359
	3.81			0.77	0.0314		0.0446
	3.19			0.45	0.0184		0.0261
	2.94			0.84	0.0343		0.0487
	2.56			1.1	0.0449		0.0636
	0.56			3.0	0.122		0.173

TABLE F.24 - THERMAL DATA

Foxhole: 20
Receiver Position: Vertical
Predicted Wall Area Exposed: 8 ft^2

Shot	Distance From: Exposed Wall (Ft)	Distance From: Top (Ft)	Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
9	4.0	2.0 - 4.0	6.45	3.0 - 5.6	0.0822 -0.153	1.76	0.145 -0.269
10	4.0	2.0	8.0	3.0 - 5.6	0.122-0.229	1.42	0.173 -0.325
		3.06		5.6	0.229		0.325
		4.0		5.6 - 7.1	0.229-0.290		0.325-0.412

TABLE F.25 - THERMAL DATA

Foxhole: 21
Receiver Position: Vertical
Predicted Wall Area Exposed: 24 ft^2

Shot	Distance From: Exposed Wall (Ft)	Distance From: Top (Ft)	Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
9	1.0	3.24	16.4	9.7	0.266	2.08	0.554
		3.49		7.1	0.194		0.404
		3.99		6.3	0.172		0.358
10	1.0	3.24	13.9	7.1	0.290	2.45	0.710
		3.61		7.1	0.290		0.710
		3.74		5.6	0.229		0.561

TABLE F.26 - THERMAL DATA

Foxhole: 22
Receiver Position: Vertical
Predicted Wall Area Exposed: 8 ft^2 + 4 ft^2 of Floor

Shot	Distance From: Exposed Wall (Ft)	Distance From: Top (Ft)	Actual Wall Area Exposed (Ft^2)	Average Energy (cal/cm^2)	Average Fraction	Correction Factor	Corrected Fraction
9	4	2.0 - 4.0	7.58	3.0 - 5.6	0.0822-0.153	2.24	0.184-0.343
10	4	2.0 - 4.0	11.1	3.0 - 5.6	0.122-0.229	1.54	0.188-0.352

APPENDIX G

BLAST DAMAGE CRITERIA FOR DESERT ROCK FIELD FORTIFICATIONS

by Pfc. Marvin Adelberg

G.1 INTRODUCTION

G.1.1 Purpose and Scope

The purpose of this appendix is to establish blast damage criteria for field fortifications suitable for inclusion in TM 23-200. This study is limited to the data contained in the Desert Rock reports of operation at the Nevada Proving Grounds (1,2,3,4) and to the analytical procedure presented by Sandia Corporation in SC-3209 (24).

G.1.2 Background

In the course of reviewing the background material for Project 3.9, Capt. Robert C. Nelson, Chief of Special Projects Branch, ERDL, recognized the possibility of applying Sandia Corporation's analytical method to present the Desert Rock observations of blast damage to field fortifications in the form of damage curves. Therefore, 1st Lt. Allan R. Fowler was directed to compile these data, and Sgt. Charles T. Messinger, under the supervision of Dr. Thomas G. Walsh, was directed to conduct the initial calculations. Upon examining the results of the initial analysis, Lt. Comdr. Christianson, AFSWP, suggested that it be extended. The analysis was extended and put in final form by Pfc. Marvin Adelberg, under the supervision of 1st Lt. Fowler.

G.2 ANALYSIS

G.2.1 Raw Data

The raw data consist of the observations of blast damage to field fortification emplacements presented in the reports on Exercise DESERT ROCK I to V. The data are consolidated in Table G.1, which is self-explanatory except for the column headed "Damage Probability." To explain this column, consider the 32nd entry, which is 3/5. This means that five unreinforced field fortifications were exposed under

Table G.1 Raw Data on Desert Rock Field Fortifications

Observation No.	Desert Rock Exercise No.	Ground Range (Yds)	Height of Burst (Yds)	Approximate Yield (KT)	Damage Probability: No. Damaged / (No. Damaged + No. Undamaged)
1-U*	V	250	100	32.4	1/1
2-U	II	95	0	1.1	1/1
3-U	V	500	100	51.5	2/2
4-U	III	150	-5.7	1.1	1/1
5-U	V	500	100	32.4	2/2
6-U	V	500	100	27.7	2/2
7-U	III	183	-5.7	1.1	1/1
8-U	V	500	100	16.3	3/3
9-U	V	600	100	24.5	3/3
10-U	V	500	175	15.4	2/2
11-U	IV	550	100	17.0	3/3
12-U	II	250	0	1.1	1/1
13-U	III	266	-5.7	1.1	1/1
14-U	V	1000	100	51.5	2/2
15-U	II	280	0	1.1	0/1
16-U	V	300	808	26.4	0/4
17-U	III	300	-5.7	1.1	1/1
18-U	II	315	0	1.1	1/1
19-U	V	1000	100	32.4	2/2
20-U	III	333	-5.7	1.1	1/1
21-U	V	1000	100	27.7	0/2
22-U	II	345	0	1.1	1/1

Table G.1 (Continued) - Raw Data on Desert Rock Field Fortifications

Observation No.	Desert Rock Exercise No.	Ground Range (Yds)	Height of Burst (Yds)	Approximate Yield (KT)	Damage Probability No. Damaged / (No. Damaged + No. Undamaged)
23-U	III	347	-5.7	1.1	1/1
24-U	V	1000	100	24.5	0/3
25-U	IV	900	100	17.0	2/4
26-U	III	366	-5.7	1.1	1/1
27-U	II	375	0	1.1	1/1
28-U	III	385	-5.7	1.1	1/1
29-U	V	800	808	26.4	0/2
30-U	IV	200	1167	30.0	1/1
31-U	III	400	-5.7	1.1	1/1
32-U	V	1000	100	16.3	3/5
33-U	V	1500	100	51.5	0/2
34-U	V	1000	175	15.4	0/2
35-U	IV	550	1167	30.0	0/1
36-U	III	433	-5.7	1.1	1/1
37-U	II	445	0	1.1	1/1
38-U	III	466	-5.7	1.1	1/2
39-U	II	485	0	1.1	0/1
40-U	V	1500	100	32.4	0/2
41-U	IV	900	1167	30.0	0/1
42-U	III	500	-5.7	1.1	1/2
43-U	II	515	0	1.1	1/1
44-U	III	533	-5.7	1.1	1/2
45-U	II	545	0	1.1	0/1

Table G.1 (Continued) - Raw Data on Desert Rock Field Fortifications

Observation No.	Desert Rock Exercise No.	Ground Range (Yds)	Height of Burst (Yds)	Approximate Yield (KT)	Damage Probability $\frac{\text{No. Damaged}}{\text{No. Damaged} + \text{No. Undamaged}}$
46-U	III	566	-5.7	1.1	1/2
47-U	II	580	0	1.1	0/1
48-U	III	600	-5.7	1.1	0/2
49-U	V	1500	100	16.3	0/2
50-U	III	633	-5.7	1.1	0/1
51-U	III	666	-5.7	1.1	0/1
52-U	IV	1700	100	17.0	0/3
53-U	IV	1700	1167	30.0	0/1
54-U	II	695	0	1.1	0/1
55-U	III	700	-5.7	1.1	0/1
56-U	III	733	-5.7	1.1	0/1
57-U	II	735	0	1.1	1/1
58-U	II	765	0	1.1	0/1
59-U	III	766	-5.7	1.1	0/1
60-U	II	850	0	1.1	0/1
61-U	III	866	-5.7	1.1	0/1
62-U	II	885	0	1.1	0/1
63-U	III	900	-5.7	1.1	0/1
64-U	III	933	-5.7	1.1	0/1
65-U	II	955	0	1.1	0/1
66-U	III	966	-5.7	1.1	0/1
67-U	II	980	0	1.1	0/1
68-R*	III	100	-5.7	1.1	2/2

Table G.1 (Continued) - Raw Data on Desert Rock Field Fortifications

Observation No.	Desert Rock Exercise No.	Ground Range (Yds)	Height of Burst (Yds)	Approximate Yield (KT)	Damage Probability $\frac{\text{No. Damaged}}{\text{No. Damaged} + \text{No. Undamaged}}$
69-R	II	100	0	1.1	2/2
70-R	II	115	0	1.1	1/1
71-R	III	117	-5.7	1.1	1/1
72-R	III	150	-5.7	1.1	1/1
73-R	III	183	-5.7	1.1	1/1
74-R	II	200	0	1.1	2/2
75-R	III	200	-5.7	1.1	0/2
76-R	III	214	-5.7	1.1	1/1
77-R	II	215	0	1.1	0/1
78-R	II	250	0	1.1	0/1
79-R	III	266	-5.7	1.1	1/1
80-R	II	280	0	1.1	1/1
81-R	III	300	-5.7	1.1	0/3
82-R	III	313	-5.7	1.1	0/1
83-R	II	315	0	1.1	0/1
84-R	III	333	-5.7	1.1	0/1
85-R	II	345	0	1.1	0/1
36-R	III	347	-5.7	1.1	0/1
87-R	III	366	-5.7	1.1	0/1
88-R	II	375	0	1.1	0/1
89-R	III	385	-5.7	1.1	0/1
90-R	IV	200	1167	30.0	1/1
91-R	II	400	0	1.1	0/2

Table G.1 (Continued) - Raw Data on Desert Rock Field Fortifications

Observation No.	Desert Rock Exercise No.	Ground Range (Yds)	Height of Burst (Yds)	Approximate Yield (KT)	Damage Probability: No. Damaged / (No. Damaged + No. Undamaged)
92-R	III	400	-5.7	1.1	0/3
93-R	III	412	-5.7	1.1	0/1
94-R	II	415	0	1.1	0/1
95-R	IV	550	1167	30.0	0/1
96-R	III	433	-5.7	1.1	0/1
97-R	II	445	0	1.1	0/1
98-C*	V	500	100	51.5	2/2
99-C	V	500	100	32.4	2/2
100-C	V	500	100	27.7	2/2
101-C	V	500	100	16.3	2/2
102-C	V	600	100	24.5	1/2
103-C	V	500	175	15.4	2/2
104-C	IV	550	100	17.0	1/1
105-C	IV	550	100	14.0	0/1
106-C	V	1000	100	51.5	2/2
107-C	V	300	808	26.4	0/3
108-C	V	1000	100	32.4	0/2
109-C	V	1000	100	27.7	0/2
110-C	V	1000	100	24.5	0/2
111-C	IV	900	100	17.0	0/1
112-C	IV	900	100	14.0	0/1
113-C	V	800	808	26.4	0/2
114-C	V	1000	100	16.3	0/2

Table G.1 (Continued) - Raw Data on Desert Rock Field Fortifications

Observation No.	Desert Rock Exercise No.	Ground Range (Yds)	Height of Burst (Yds)	Approximate Yield (KT)	Damage Probability: No. Damaged / (No. Damaged + No. Undamaged)
115-C	V	1500	100	51.5	1/2
116-C	V	1000	175	15.4	1/2
117-C	V	1500	100	32.4	0/2
118-C	V	1500	100	16.3	0/2
119-C	IV	1700	100	14.0	0/1
120-CR*	III	100	-5.6	1.1	1/1
121-CR	II	115	0	1.1	1/1
122-CR	III	117	-5.6	1.1	2/2
123-CR	V	400	100	24.5	1/1
124-CR	II	200	0	1.1	1/1
125-CR	III	200	-5.6	1.1	1/1
126-CR	III	214	-5.6	1.1	0/2
127-CR	II	215	0	1.1	2/2
128-CR	V	0	808	26.4	0/1
129-CR	V	100	808	26.4	2/3
130-CR	III	300	-5.6	1.1	0/1
131-CR	III	313	-5.6	1.1	1/2
132-CR	IV	200	116.7	30.0	1/1
133-CR	II	400	0	1.1	0/1
134-CR	III	400	-5.6	1.1	1/1
135-CR	III	412	-5.6	1.1	1/2
136-CR	II	415	0	1.1	0/2
137-CR	IV	550	116.7	30.0	1/1

Table G.1 (Continued) - Raw Data on Desert Rock Field Fortifications

Observation No.	Desert Rock Exercise No.	Ground Range (Yds)	Height of Burst (Yds)	Approximate Yield (KT)	Damage Probability $\frac{\text{No. Damaged}}{\text{No. Damaged} + \text{No. Undamaged}}$
138-CR	III	633	-5.6	1.1	0/1
139-CR	II	635	0	1.1	0/1
140-CR	II	645	0	1.1	0/2
141-CR	III	645	-5.6	1.1	0/2
142-CR	IV	1700	116.7	30.0	0/1

* Letter designation refers to type of fortification:

U - Unreinforced
R - Revetted
C - Covered
CR - Covered and Revetted

identical conditions, three of which were considered damaged. An unreinforced field fortification consisted of no more than an excavation, and was considered damaged if it was at least half full of earth. A reinforced field fortification consisted of an excavation which was either covered, revetted, or both covered and revetted, and was considered damaged if any significant part of the structure failed. Detailed drawings of all of the Desert Rock fortifications are presented in the reports referenced above.

G.2.2 Blast Damage Curves

The blast damage curves are presented in Figs. G.1 to G.8. They are a result of the application of the analytical procedure to the raw data. With probability of damage as ordinate, peak overpressure, maximum earth particle velocity, and slant range, all scaled to 1 KT, were chosen as abscissa. For each figure, type of field fortification or type of burst was chosen as the parameter.

When applying the Sandia Corporation's method, we assume there exists a reversed normal distribution curve which best fits the data. The next step is to find the mean and the standard deviation. Once these values are determined, the particular curve is fixed. The theory of why a reversed normal distribution curve is selected and the theoretical derivation of the best mean and standard deviation will not be discussed in this appendix. The equations which yield the best values of the mean and standard deviation are:

$$m = \sum_{j=1}^{k-1} T_j \; P_j \qquad ; \quad \sigma^2 = \left[\sum_{j=1}^{k-1} T_j^2 \; P_j \right] - m^2$$

m = mean
σ = standard deviation
P_j = difference in probabilities of adjacent sets
T_j = value of the parameter dividing two adjacent sets
k = number of sets

As an example, consider the probability of the damage curve for reinforced fortifications with peak overpressure as abscissa for the underground burst, which is shown in Fig. G.5. Tables G.2 and G.3 are the complete work sheets used for developing this damage curve. Their purpose is to determine the values of m and σ according to the above equations, and to then obtain nine selected points of the corresponding reversed normal distribution curve which best represent the data.

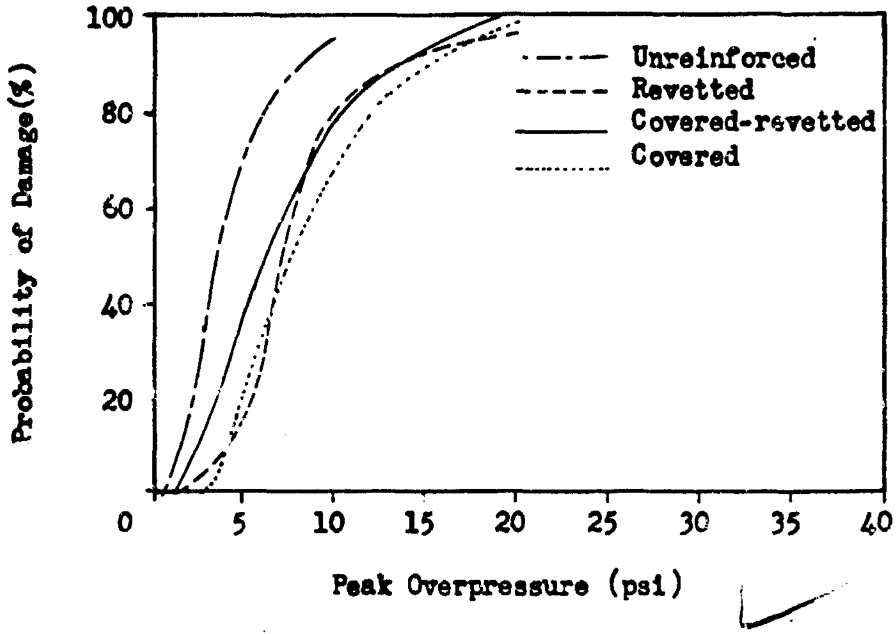

Fig. G.1 Probability of Blast Damage to Field Fortifications vs Peak Overpressure Scaled to 1 KT Based on Desert Rock Data From the Underground, Surface, and Air Bursts.

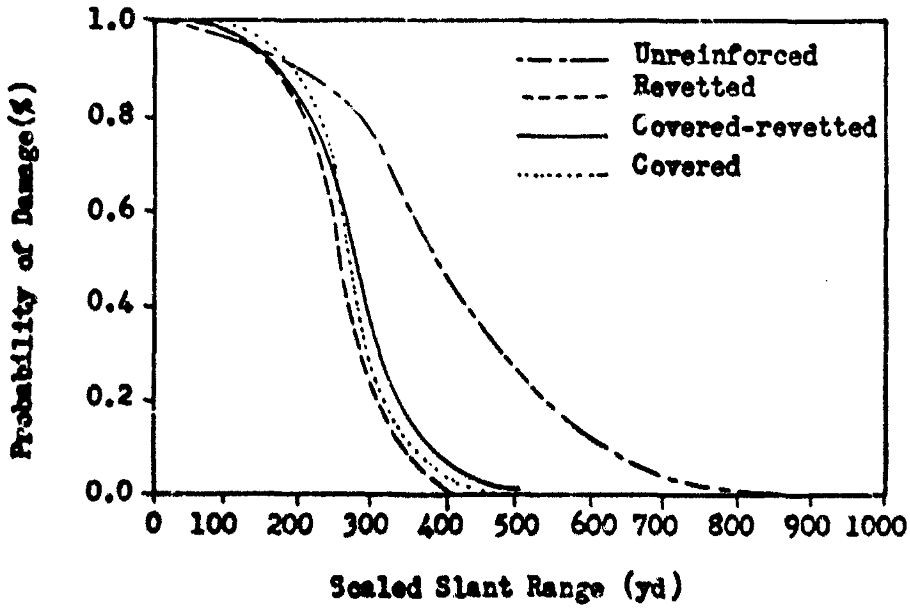

Fig. G.2 Probability of Blast Damage to Field Fortifications vs Slant Range Scaled to 1 KT Based on Desert Rock Data From the Underground, Surface, and Air Bursts.

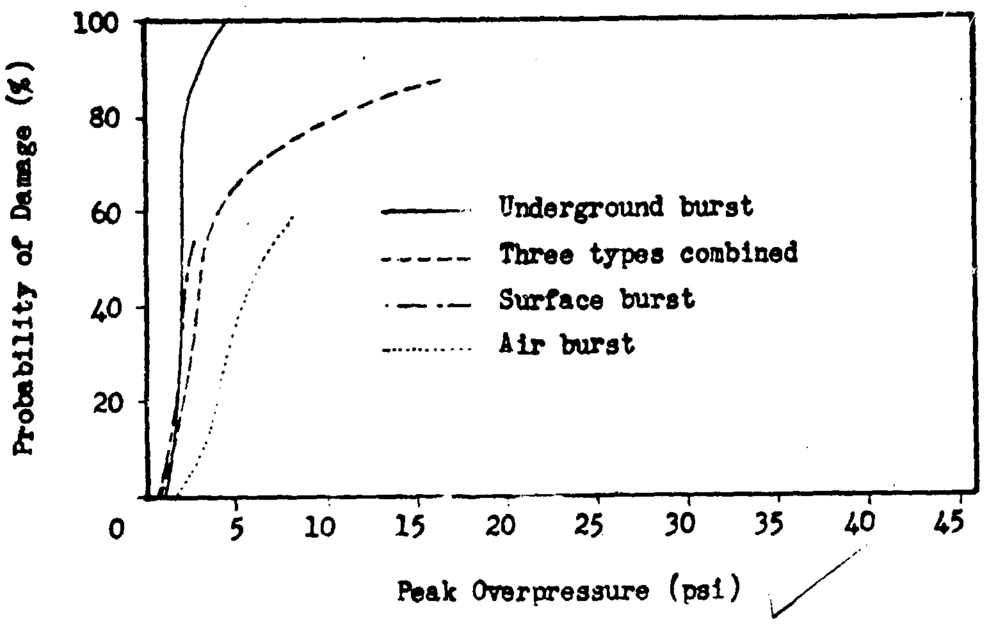

Fig. G.3 Probability of Blast Damage to Unreinforced Field Fortifications vs Peak Overpressure Scaled to 1 KT for the Desert Rock Underground, Surface, and Air Bursts.

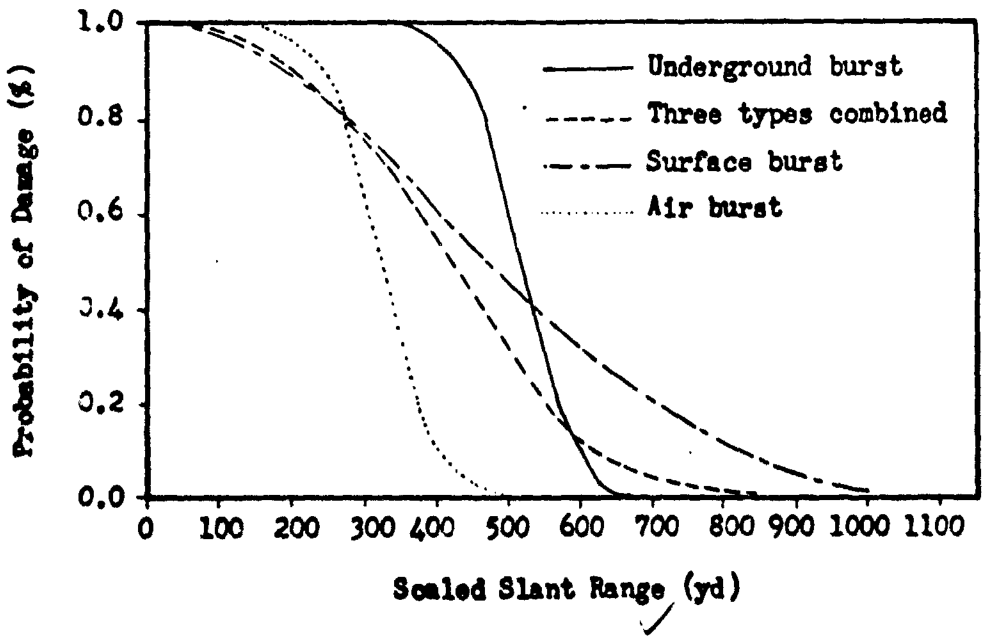

Fig. G.4 Probability of Blast Damage to Unreinforced Field Fortifications vs Slant Range Scaled to 1 KT for the Desert Rock Underground, Surface, and Air Bursts.

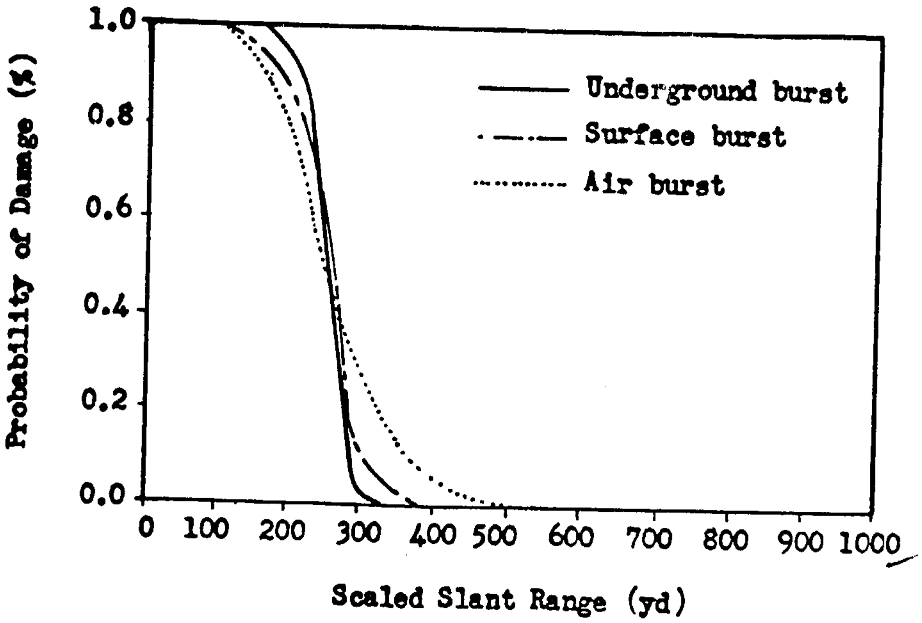

Fig. G.5 Probability of Blast Damage to Reinforced Field Fortifications vs Peak Overpressure Scaled to 1 KT for the Desert Rock Underground, Surface, and Air Bursts.

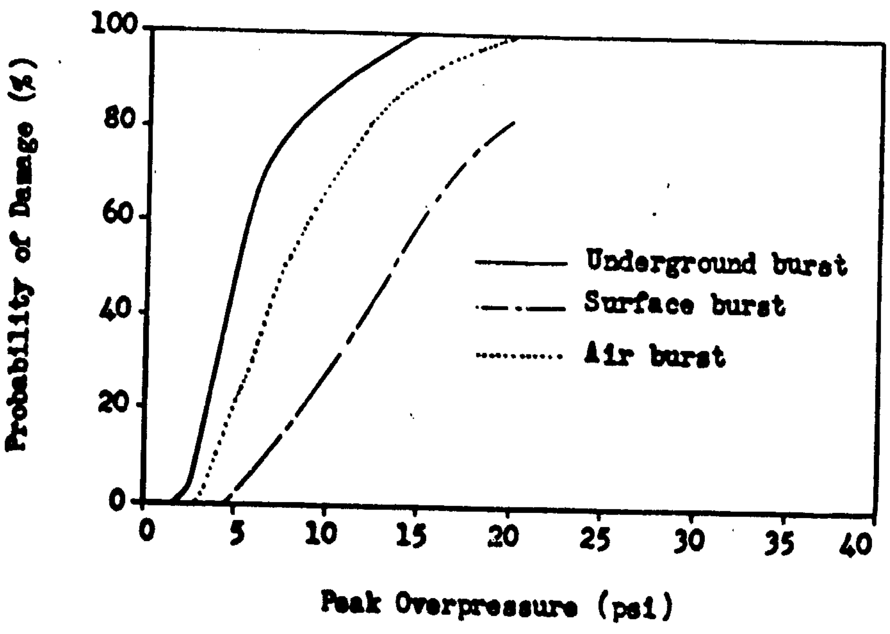

Fig. G.6 Probability of Blast Damage to Reinforced Field Fortifications vs Slant Range Scaled to 1 KT for the Desert Rock Underground, Surface, and Air Bursts.

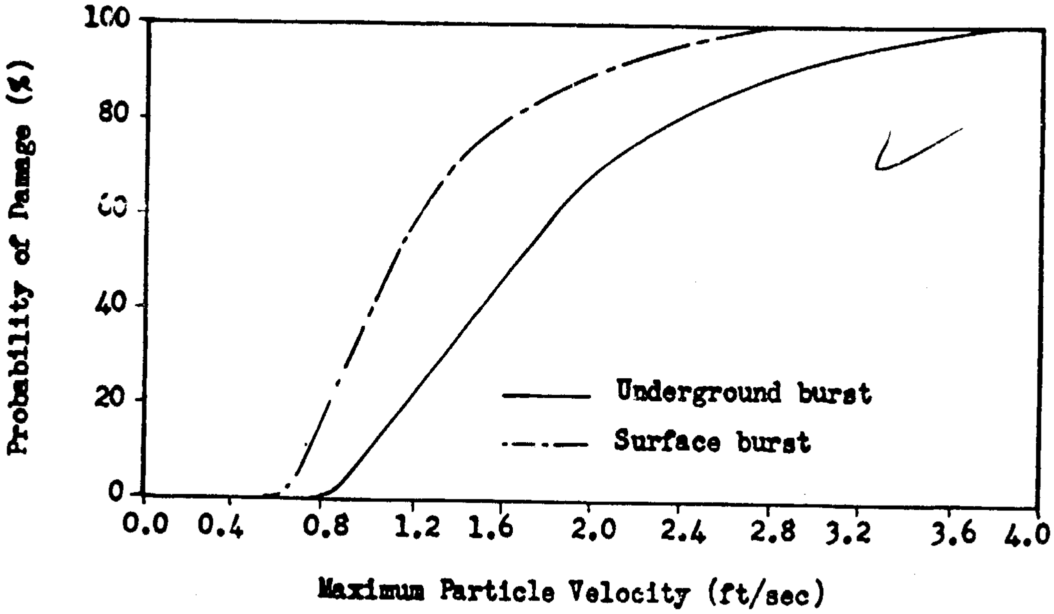

Fig. G.7 Probability of Blast Damage to Unreinforced Field Fortifications vs Maximum Particle Velocity Scaled to 1 KT for the Desert Rock Underground and Surface Burst.

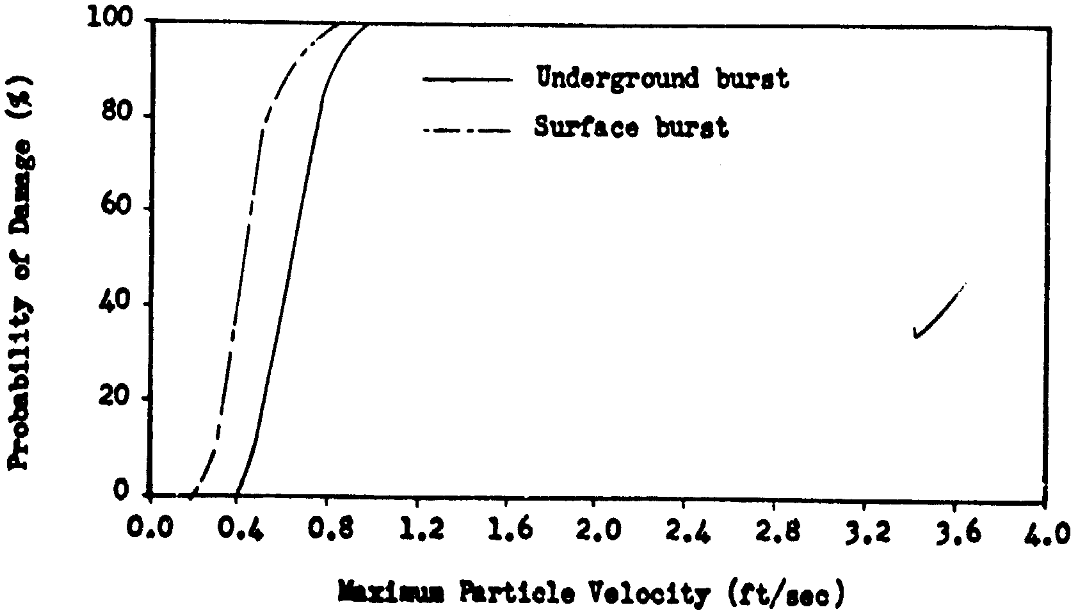

Fig. G.8 Probability of Blast Damage to Reinforced Field Fortifications vs Maximum Particle Velocity Scaled to 1 KT for the Desert Rock Underground and Surface Burst.

Table G.2 - Part I of Work Sheet for Developing Underground Burst Damage Curve for Fig. G.5

Observation Number	Peak Overpressure P.S.I.	P	$\bar{P}$	$\bar{P}$ Regrouped
		No. Damaged / (No. Damaged + No. Undamaged)		
1	50	2/2		
2	45	1/1		
3	35	2/2	8/8	8/8
4	30	1/1		
5	22	1/1		
6	17	1/1		
7	15	0/2	1/3	
8	15	1/1		
9	14	0/2		4/12
10	13	1/1	2/4	
11	9.2	1/1		
12	8.2	0/3	1/5	
13	7.9	1/2		
14	7.8	0/1		
15	6.9	0/1		
16	6.5	0/1		
17	6.2	0/1	2/8	2/8
18	5.6	0/1		
19	5.6	1/1		
20	5.5	1/2		
21	5.3	0/1		
22	5.2	0/1		
23	5.0	0/1	0/6	0/6
24	2.9	0/1		
25	2.3	0/2		

G.3 DISCUSSION

G.3.1 Data Analysis

As can be seen in Figs. G.1 to G.4, the Desert Rock data show very little difference between the damage susceptability of the three types of reinforced fortifications. Therefore, the Desert Rock data, which was presented to include four types of fortifications, should be considered to include only two, unreinforced and reinforced.

The damage curves presented with peak overpressure as abscissa, Fig. G.3, and G.5, are rather steep and lend themselves to the setting up of damage categories, which are shown in Table G.4 below.

Table G.3 - Part II of Work Sheet for Developing Underground Burst Damage Curve for Fig. G.5

P	Range	Range Extended	Range Inverted
1.000	50-17	- [illegible]	0 - 0.0625
0.333	15-7.9	16 - 7.8	0.0625 - 0.128
0.250	7.8-5.5	7.8 - 5.4	0.128 0.185
0.000	5.3-2.3	5.4 - 0	0.185

T_j	P_j	T_jP_j	$T_j^2P_j$	
0.0625	0.667	0.0418	0.00262	= 0.0987
0.128	0.083	0.0106	0.00136	= 0.0526
0.185	0.250	0.0463	0.00855	

T-M	T-M	T	1/T	Probability (%)
-3.0	-0.158	-	-	100
-2.0	-0.115	-	-	97.5
-1.5	-0.0790	0.0197	50.6	93
-1.0	-0.0526	0.0461	21.6	84
0	0	0.0987	10.1	50
1.0	0.0526	0.151	6.61	16
1.5	0.0790	0.178	5.61	7
2.0	0.115	0.214	4.67	2.5
3.0	0.158	0.257	3.89	0

Table G.4 - Damage Criteria Based on Peak Overpressure

Probability of Damage (per cent)	Critical Peak Overpressure (psi)					
	Unreinforced Fortifications			Reinforced Fortifications		
	Underground Burst	Surface Burst	Air Burst	Underground Burst	Surface Burst	Air Burst
10	3	3	7	6	14	8
50	4	5	13	9	27	16
90	5	17	25	21	45	29

As brought out by Figs. G.3 and G.4, the data on unreinforced field fortifications indicate that the type of burst (air, surface, underground) may be significant. The air burst curve stands apart from the surface and underground burst curves when plotted on either a peak overpressure or slant range basis. The implication is that

both the surface and underground bursts are more damaging than the air burst. This trend disappears as we approach ground zero (high peak overpressures and low scaled slant ranges). Since this implication is serious, it must be stressed that this is based on a limited amount of data and, hence, is susceptable to sizeable errors.

For reinforced field fortifications, the curves for air, surface, and underground bursts practically coincide when slant range is used as abscissa; but they again separate when peak overpressure is used as abscissa. The reason for the separation in the later case is not evident. It should be pointed out that although Fig. G.5 is for reinforced field fortifications, the air burst curve is based on data which are primarily taken from "covered" field fortifications, while the surface and underground burst curves have very little data from the "covered" field fortification group. These two curves are based solely on data from the "revetted" and "covered and revetted" group. The surface and underground burst curves each have a relatively poor correlation, and there can be noted a tendency for the "revetted" fortification data to displace these two curves further to the right and the "covered and revetted" fortification data to displace these curves toward the left.

It is interesting to note that one of the necessary conditions that the variable selected as abscissa for the damage curves be the true damage causing factor (if there is only one and not a combination of two or more) is that the air, surface, and underground burst curves coincide. The curves were considered as not coinciding in all cases but one, the implication being that slant range, peak overpressure, or maximum earth-particle velocity is not the one true influencing factor. One difficulty in drawing this as a conclusion is that other errors may be causing these deviations and the true curves may really be coincident. Furthermore, since coincidence is a necessary condition but not a sufficient one, the abscissa for the one case where the curves did coincide is not necessarily the true influencing factor for that case. In other words, we have a negative check for the true variable but not a positive one.

G.3.2 Error Analysis

Because of the time consuming complexity of treatment of the data, a mathematical error analysis is not presented; but mention of the contributing factors can be made.

1. The human error in obtaining, recording, and evaluating the raw data may be very significant. There were many cases where it was difficult to determine decisively whether a fortification should be considered "damaged" or "undamaged".

2. No allowance was made for the variation in the designs and in the strengths of the materials used for covers and revetments. Likewise, no allowance was made for the variation in ground conditions, in orientation of the fortifications, or in the relative dimensions of the fortifications.

3. When applying the Sandia Corporation mathematical method, the lack of sufficient raw data results in the curves being too flexible. Errors of the order of 25 per cent are not unlikely. This

would correspond to an error band for each curve, the width corresponding in some cases to the difference between the curves which are to be compared. The method really falters at the extreme ranges of probability, and visual modifications based on the raw data were made in these regions. The distribution of the raw data is shown in Table G.5.

Table G.5 - Distribution of Raw Data

Type of Burst	Type of Fortification			
	unreinforced	revetted	covered	covered and revetted
Air	58	2	41	8
Surface	18	13	0	10
Underground	28	20	0	15

4. Peak overpressures and maximum earth particle velocities were taken from curves in TM 23-200 dated 1 October 1952 which have an "estimated reliability" of ± 25 per cent and ± 50 per cent respectively.

The influence of the above four points is not evident in the figures because of the complexity of the process through which the data must pass in order to yield a curve. As a matter of fact, any monotone set of three groups or more will produce a damage curve regardless of whether the variable under consideration is or is not producing the damage. This is because the method assumes the reversed normal distribution to begin with and utilizes the data to determine the two constants m and σ . Once these are determined, the corresponding reversed normal distribution curve is presented as being representative of the data. By modifying the curves at their extremes, satisfactory values for high and low probability were obtained. The data for intermediate values of "probability of damage" were rather sparce, and a better correlation would have been obtained had there been more data. The probable error in this appendix is estimated at ± 30 per cent for Figs. G.2, G.4, G.6; ± 45 per cent for Figs. G.1, G.3, G.5, and for Table G.4; and ± 60 per cent for Figs. G.7 and G.8.

G.4 CONCLUSION AND RECOMMENDATION

It is concluded that damage criteria for the Desert Rock field fortifications are shown in Table G.4, with an estimated probable error of ± 45 per cent.

It is recommended that, until better data can be obtained, the blast damage criteria presented here be appropriately included in TM 23-200.

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SECTION 144b, ATOMIC ENERGY ACT, 1954

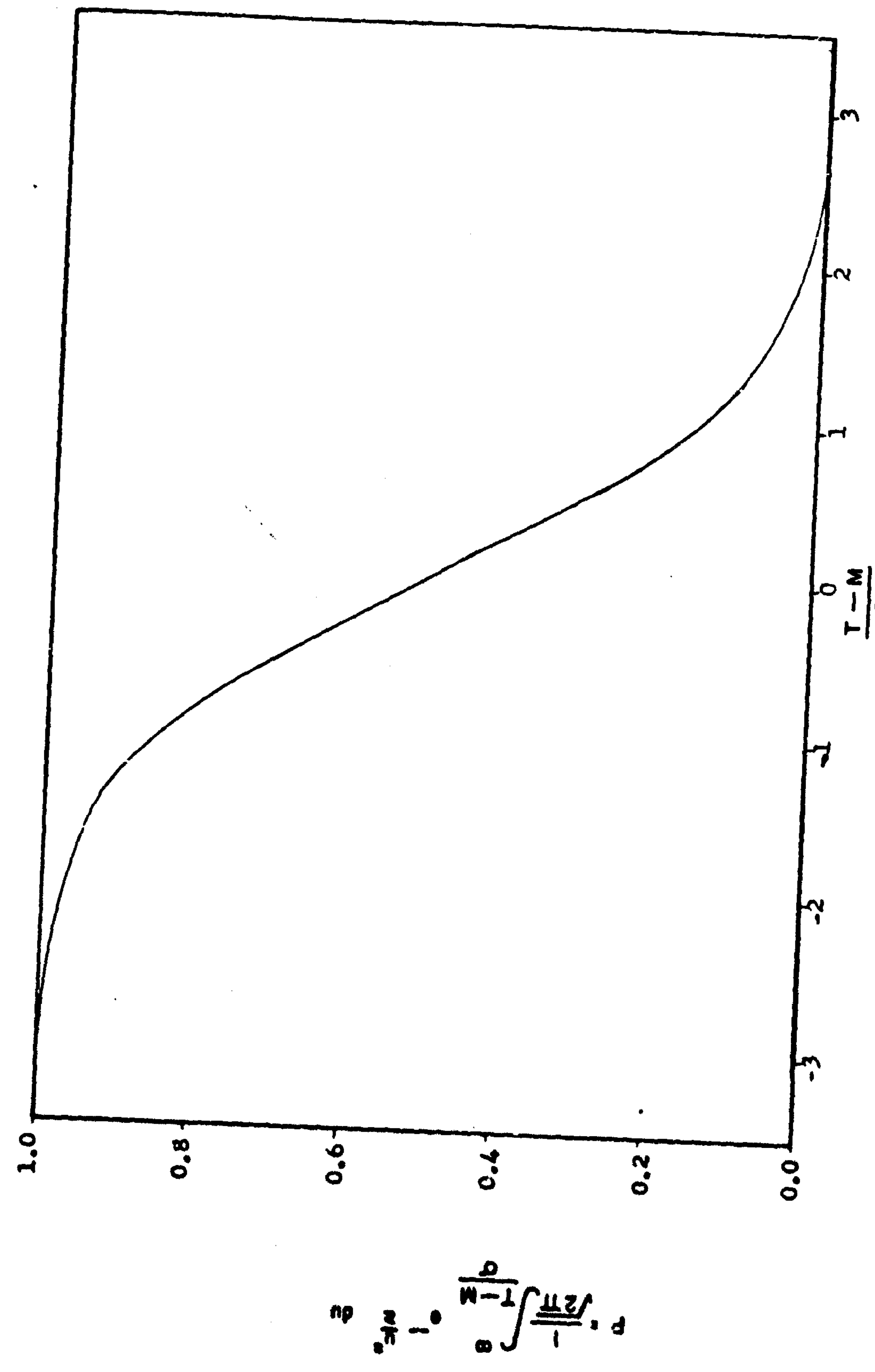

Fig. G.9 - Reversed Normal Distribution Curve

SECRET - RESTRICTED DATA

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